Plant Population Assessment Methods to Help Inform Best Harvest/Management Practices and Track Changes over Time.

Introduction

Culturally and economically-valued wild plants can easily be overharvested—even unintentionally—without understanding their deeper complex relationships and cycles within the environment, and the resulting impact harvesting can have on them. Traditional wisdom, including traditional ecological knowledge, can be very valuable in guiding place-based decisions and underlying philosophies that have been learned and practiced over many generations. The contribution of "Western science" can add another layer of understanding to these complex relationships. However, research in this realm is inadequate, leading to poorly defined and uncertain guidelines of what constitutes a "sustainable" or responsible harvest. One difficulty is that it varies so much considering all the variables at play (e.g. the species under consideration, plant part harvested, plant life cycle, long-term regeneration rates, and countless environmental factors). Even so, there are some general considerations that may help guide decisions. One important consideration is determining baseline plant population data. For example, how many plants of the target species are in a given area?) This is easier said than done, therefore this methodological protocol was written to help forest farmers and technical service providers inventory baseline populations of wild stewarded forest botanicals and assess population regeneration over time. These methods were created in collaboration with seasoned and beginning forest farmers, botanists, and FairWild (an international certification program that ensures wild plants and plant products are sustainably harvested). The intended audience is for lay people and professionals alike.

Because such protocols would differ so much based on plant type involved, this one only focuses on herbaceous perennials (e.g. goldenseal (*Hydrastis canadensis*), black cohosh (*Actaea racemosa*), American ginseng (*Panax quinquefolius*), ramps (*Allium tricoccum*), and other similar plants). (Population assessment protocol for different types of plants (besides herbaceous perennials) may be created in the future.) Goldenseal is the target species selected for the case study assessment (embedded into the steps below as an example to help visualize the process). Certain aspects of this protocol can be applied to many other types of target species and harvesting methods as well, with minor adaptations for other aspects (such as larger plot sizes for larger plants—including woody perennials—that have a lower density per area). Formulas are included in the appendix to help users understand the math behind it all, so they can adapt the methods to different plant types and circumstances if desired.

The first goal in this assessment is to measure the geographic area of the target species' population of interest. The second is to estimate the density and number of individuals of the target species within that population. From here, several inferences can be made regarding the population, especially if data is collected over multiple years and comparisons can be made. The data is captured through smartphone apps and/or traditional measuring and data collection techniques. Please recognize that it is very difficult to get extremely accurate information without counting/measuring each individual within a population, as this is often not a logical option (depending on the size and number of individuals within the population). Therefore, the following methods require several layers of estimation and extrapolation. While the resulting data may naturally not be extremely accurate, it can still be helpful in general assessments and provide the ability to see significant changes over time (e.g. increases or decreases in the population density and health). One way to visualize this concept is to think of the "Jelly Bean Jar Game" where contestants estimate the number of jelly beans in a large clear jar (without opening it) by counting the number of jelly beans in one subsample (e.g. jelly beans in view on the bottom layer of the jar), and then multiply that by the number of layers in the jar to estimate the total number, always making room for a range of error (more or less). The person with the closest correct number wins the jar of jelly beans. While assessing plant population numbers is not quite as simple as that game, the general concept applies, of counting a subsample of the whole, and extrapolating estimates from that. You may need to read through these methods several times and test them out in the field to be able to fully comprehend them.

Overview of Steps

1. Measure population area of target species. (Map out where the patches are, draw a perimeter around the whole population of interest, and determine the geographic area within that created perimeter.)
2. Gather data in subsample plots. (Find out how many individuals there are in a given small sample area.)
3. Estimate density intensity percentages of the target species within the whole population. (How does the density of the target species vary in different areas within the population?)
4. Extrapolate numbers to the whole population. (Determine an informed estimate of the number of individuals of different sizes/ages within the whole population.)

Equipment list:

- Three sticks or stakes ("Step-in posts" used by farmers for poly wire electric fencing work well.)
- String (Bright-colored mason string works well.)

- Measuring tapes
- Smartphone with various apps (or long surveyor tape measures if a smartphone is not available)
- Paper and pencil

Protocol Steps in Detail

1. **Measure Population Area of Target Species.** You will need to determine the extent of the population you are going to assess. This will involve knowing where the target species is concentrated and mapping a perimeter around them, and then determining the geographic area within that perimeter. The resulting area calculation will be used in step 4 to generate population census results.
    1.1. <u>General exploratory observations (Find and mark target species locations generally).</u> If you are unsure of the extent of the population, begin by exploring the area to search for the target species. If you have a smartphone, you may use an app (for example, “GPS Tracks”) that uses GPS tracking that allows you to mark waypoints as you find individuals or patches; some apps allow you to take pictures at the waypoints as well, which may be helpful to remember the general density of the patches you found. When you are done exploring the area, and feel like you have covered the extent of the population, you can zoom out on the map to see a bird’s-eye view of where you have found patches of the target species. This will be helpful as a preliminary step to help you know where to walk to measure the perimeter of the population you want to assess (see Figure 1).

Figure 1. Dropped pins (waypoints) roughly marking where goldenseal patches were found.

1.2. Create a perimeter map of the population and calculate its geographic area. Walk the perimeter of the population using an app that uses GPS to track steps and which measures the area of a resulting polygon (such as "GPS Fields Area Measure Map"). Before you begin, choose a memorable landmark or leave some kind of marking (like flagging tape tied to a branch), so you are sure to end at the same point you began to close off the polygon. While you are walking the perimeter, make more casual observations of the target species within the population to get a better feel for the varying densities within. When you have completed the polygon, the app will calculate an estimated area for you (see Figure 2.) If you do not have a smartphone, you can mark the perimeter with flagging or other appropriate markers, then measure the distance between the corners with a long measuring tape, and the angles from the corners to the next corner with compass points. From there, you can calculate the area within the polygon using basic geometry. There may be more than one target population/polygon that may be combined and calculated as one population, depending on your circumstance and personal judgements. (For example if the target species is only occurring on the north slopes of three different nearby hill sides, that could result in three polygons that could—for the purposes of these methods—all be considered one population).

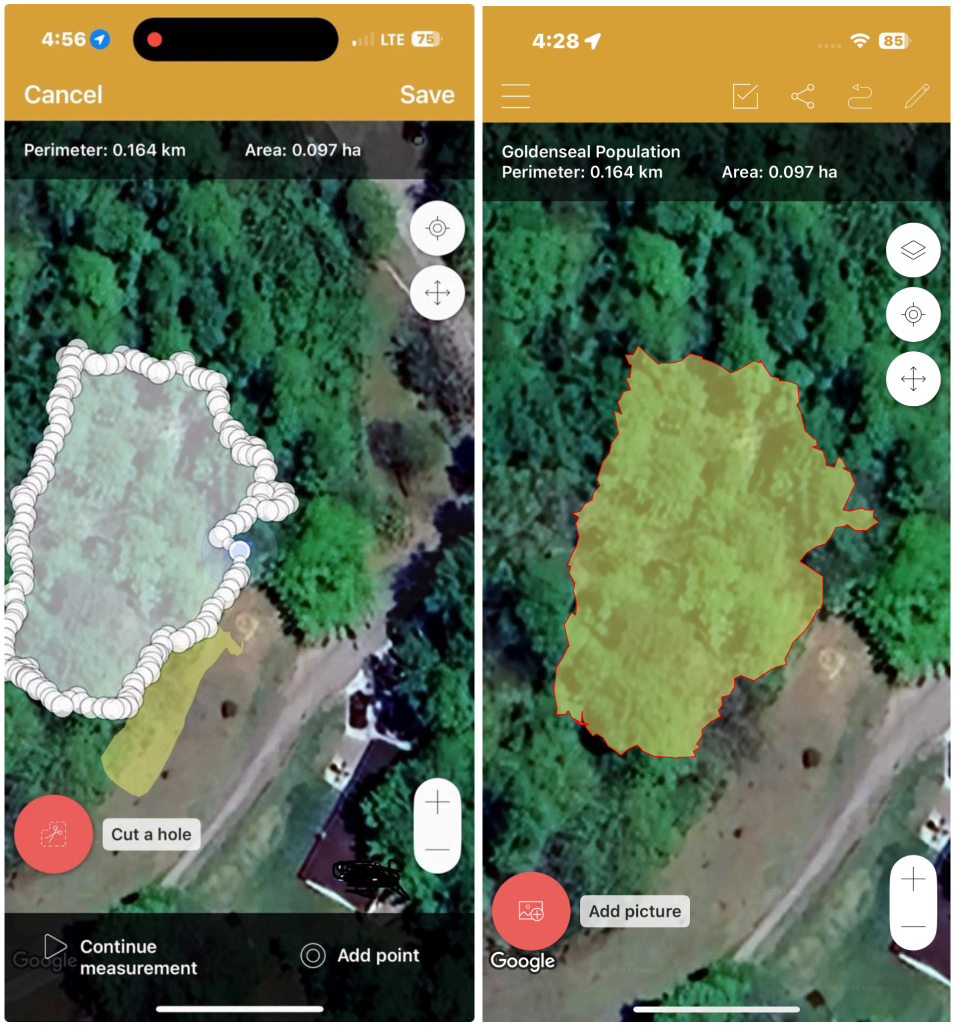

Figure 2. The "GPS Fields Area Measure Map" App tracks footsteps (left, white dots) to measure the perimeter and area of the polygon (right), estimating the area, in this example, to be 0.097 Hectares (970 square meters) (top right).

1.3. Document site attributes. At some point, be sure to write down site attributes such as the percentage of canopy cover overhead, general notes about co-occurring species, slope aspect, and other information you may feel is relevant to reflect the condition of the site. This information can go into a written general description for the population that may inform future decisions.

2. **Gather Data in Subsample Plots.** Now it is time to "count the bottom layer of jelly beans in the jar." The tricky thing here, though, is that there are usually varying densities of the target species (the “jelly beans”) within a population, unlike a jelly bean jar where each layer is generally the same density. To do this, you will be creating a stick and string plot reader tool to help you count individuals within four different density intensities within the population. The data you gather here will be used to extrapolate the numbers for the whole population in step 4.

2.1. Create the stick and string plot reader tool. Obtain three sticks or stakes that you can push into the ground. “Step-in posts” (used by farmers for poly wire electric fencing) work very well for this (see Figure 3). One stick will represent the center of a circular plot; the other two sticks will represent the outer edges of the circle as they swivel around the center, tied together by strings. The two strings tied between the center stick and the outer two sticks will be the radius of the circle. The area of the circle will be a square meter. The radius of the circle (from stick to stick including the string), therefore, should be 56.4 cm long. (The area of a circle is pi times the radius squared ($A = \pi r^2$). This may take some time to get the correct measurements as tying knots often unpredictably change the length of the string.

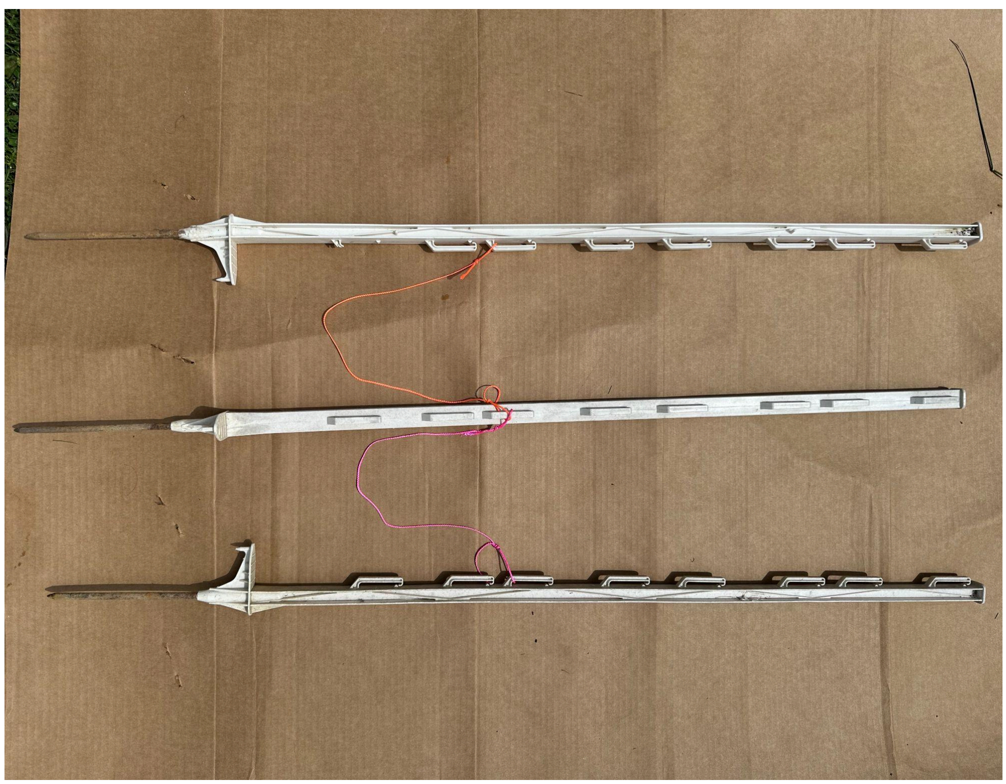

Figure 3. Stick and string plot reader tool consisting of three step-in posts and two strings tying them together.

2.2. Find varying density intensities within the population to measure. Find places where there are high, medium, low, and very low densities; four different “density intensities” (DI) within the population. You can best visualize the densities by the percent cover they have in a given area. Table 1 shows the four DIs with the respective coverage values based on logical variation of natural herbaceous perennial plant populations after testing this out on several different species. Figure 4 shows a visual representation of the goldenseal density intensities.

Table 1. Density Intensity (DI) Values	
Density Intensities (DI)	% Coverage of ground
High	60–100%
Medium	25–60%
Low	5–25%
Very Low	0–5%

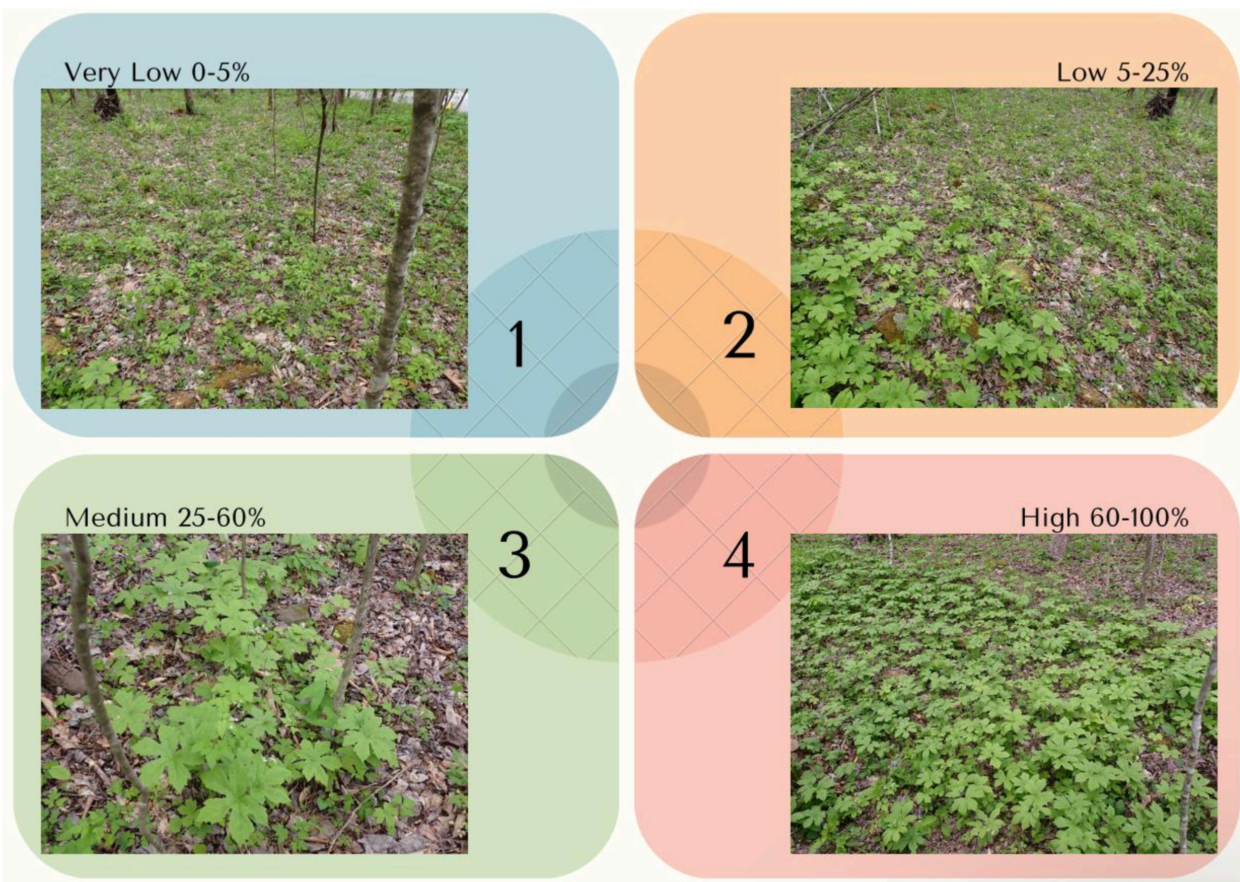

Figure 4. Visual representation of the goldenseal density intensities.

2.3. <u>Practice determining size-class categories.</u> It will be valuable to not only know how many individuals may be in a population, but also how many of those are in various developmental stages: mature reproducing (flowering or fruiting), mature but not reproducing, intermediate, and young (see figures 5–8 for how this applies to goldenseal). This will need to be determined species by species, and guidelines can be created for each. (Note: "Individuals" may actually be two stems from the same underground rhizome, so while technically, they may be one plant or one individual, in this case, they may be counted as two since you won't be digging them up at this point to find out. But functionally, two stems/leaves coming out of one rhizome may reflect a larger underground rhizome anyway, so it may balance out). You will need to get a feel for these four different categories in the field before starting data collection in your plots.

Figure 5. Young Size/Age Category: could include seedlings or just noticeably smaller plants. Note— size varies depending on the season.

Figure 6. Intermediate Size/Class Category: Plants that are in a transitional "juvenile" stage between young and mature. The exact measurements separating young, intermediate, and mature may need your own judgment based on the population observations at hand.

Figure 7. Mature Non-Reproducing Size/Class Category: Plants that seem to be the size/age of reproducing individuals, but with no evidence of experiencing a reproductive stage that year.

Figure 8. Mature Reproducing Size/Class Category: Plants that have evidence of experiencing a reproductive stage for that year (left to right: flower, young fruit, mature fruit, or a fruit stem where a fruit used to be attached). Note— Goldenseal flowering occurs in the spring when the leaf hasn't fully expanded yet, so the leaves will look quite small as if they are in the "Intermediate" stage. Adjust age/size categories based on specific plant characteristics.

2.4. <u>Gather data in plots.</u> Randomly choose a location for three plots within each DI (for a total of 12 plots). Mark your starting point (suggested 12 noon position in a certain cardinal direction, and with a unique rock or stick laid down or poking in the dirt) and methodologically go clockwise around, counting each individual in the circular plot, designating what size class they are in, to be marked in a smartphone app or on paper. It is suggested that at least two people help gather this data—one to count and call out what each plant's size/age category is, and another acting as scribe). It may be helpful to have the scribe repeat what the counter says so the counter knows she/he caught it correctly, and so the counter doesn't go too fast. The width of the pie slice can be wider or narrower depending on the target species' density within the plot (this is just to help make sure there is no double counting or missing individuals (see Figure 9, and follow the link for a video representation of data collection using this method https://drive.google.com/file/d/1mAAiP3g6aU85LZ2DtTxFHPGBS1gmJyRE/view?usp=sharing)

Figure 9. Stick and string plot reader tool forming a plot in a dense goldenseal patch. The middle stick represents the center of the circular plot, while the other two swivel around the center on their strings to complete the circle. Notice the orange flagging near the base of the right "stick" or post, which is tied onto a small loose tree branch stuck in the ground to mark the beginning and end of the plot reading. (Video linked above.)

3. **Estimate Density Intensity Percentages of the Target Species within the Whole Population.** The next step is to "count the number of jelly bean layers in the jar" for each density intensity (DI), in other words, determine how the density of the target species varies in different areas within the population. This information will be used in step 4 to extrapolate plant numbers for the whole population.
   3.1. To help you make more accurate estimates of the DI percentages within the population (e.g what is the total area of all patches with high-density intensities, and what percentage of the whole population does that represent), use the perimeter area app (used in step 1.2) to mark and measure the DI percentages

within the population. To do this, walk around patches of the various DI categories to calculate the area of each patch within the population. To make it easier, you do not have to walk around patches of all four DI types. For example if the entire range has less area with high density, medium density, and low density, but the very low DI covers the largest area within the population, walk around the smallest density areas first (it would be high, medium, low in this case). You do not need to walk around the “very low” patches in this example due to that population being the largest & it covers the rest of the assessed area (see Figure 10 for illustration). The resulting area measurements for each DI category can be added (e.g. all the high DI patch areas can be added together to get a total, and you can do the same thing for all the medium and low DI patches), and then subtract that from 100% to get the remaining very low DI (assuming the very low DI covers the largest area. This “bird's eye view” method will help you estimate the percentages of each DI in the population if you have polygons around each DI patch marking them. (You may also want to use the app “GPS Fields Area Measure Map” suggested above to help calculate the areas of each DI. each DI.) This step may work better for some situations than others; you will need to be the judge on that. If this method does not work with your circumstance (e.g. the size of your population is too large to walk around each patch of target species), use the alternate approach in step 3.2 below.

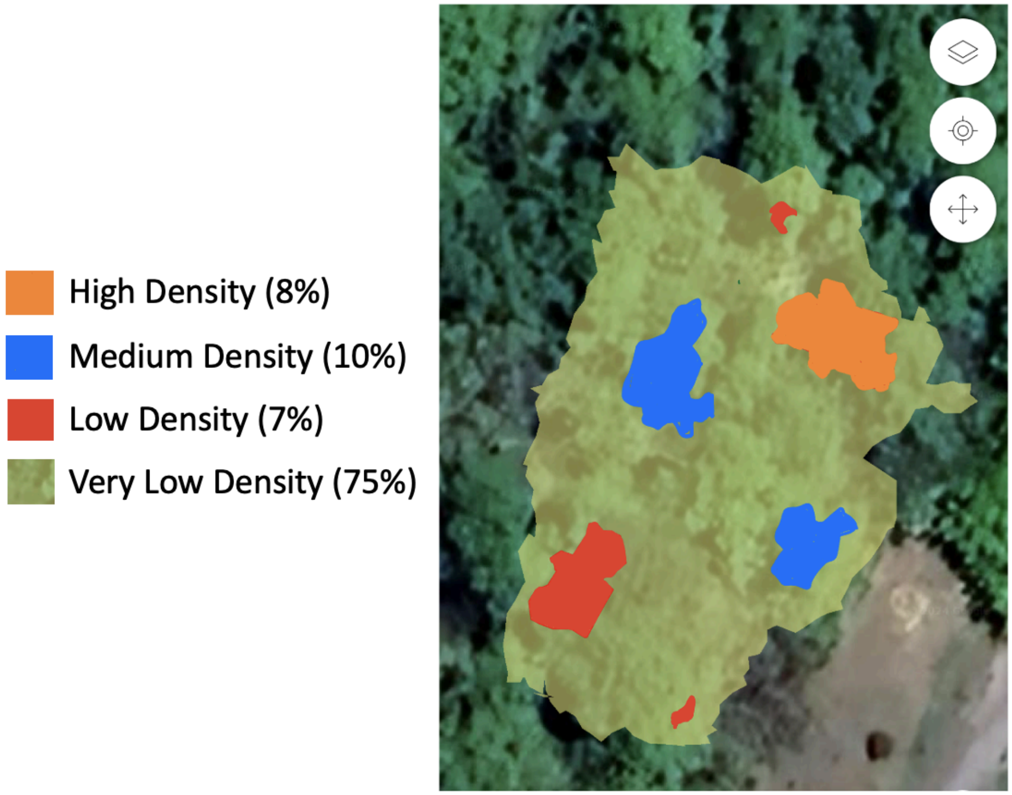

Figure 10. Patches of High, Medium, Low, and Very Low Density Intensities (DI) within the entire population. Note that Very Low covers the spaces between the other DIs, due to it having the highest area coverage. The Very Low DI percentage can be calculated simply by subtracting the total of the others from 100.

3.2. **Alternative Method from 3.1**: Determine a representative sub-polygon within the larger polygon to estimate DI percentages without walking the perimeter of each patch.

3.2.1. Determine a representative sub-polygon. Since it is difficult to estimate the DI percentages for the full population, especially over a large geographic area, a subsample polygon (preferably a square or rectangle) that you feel represents the approximate percentages of the four density intensities of the whole population can be selected. (It is easier to estimate the smaller polygon than the full population, visually.) This sub-polygon should be small enough that you can see all the plants within one frame of view as you are standing in front of it (perhaps around 50 square meters).

3.2.2. Estimate the DI percentages within the sub-polygon. Without the presence of natural landmarks (e.g. fallen logs and identifiable trees or large rocks that can “connect the dots” to make a square or rectangle), you may put flagging down on the corners and center of the sub-polygon. Using imaginary lines (or real ones using string) in the sub-polygon, divide it into quadrants to help you visualize the percentages of each DI within the sub-polygon (to visualize 25%). If you feel this subsample polygon represents the DI percentages of the whole population (from your perspective from step 1.1 and subsequent steps) then these same approximate percentages can be applied to the full population. (To help calibrate a more accurate estimate, if more than two people are there, have the people present estimate the DI percentages independently and then compare differences.) Again, as explained in the protocol introduction, these estimates are not going to be exact, but it can still be helpful in general assessments and provide the ability to see significant changes over time.

3.3. <u>Take photos and panoramic videos from the same locations each year.</u> Consistent visual records of the population will add depth to the data collection and help inform long-term decisions. At some point during the population assessment (perhaps most logically during step 3), mark specific locations to take annual (or more frequent) representative photographs and slow-spanning panoramic videos of different areas within the population that you feel represent the varying dynamics and feel for the broader population. Mark these areas with an exact GPS coordinate and permanent rebar or stake and write down the compass direction you took the photo from so you can take it from the same vantage point each year. Take these photos/videos at the same time each year for visual comparisons; you may be able to see changing trends over time. One app that would be helpful to use for this is Solocator. It marks the compass direction, the gps coordinates, and allows you to take notes, and then embeds all that data in the picture (see figure 11).

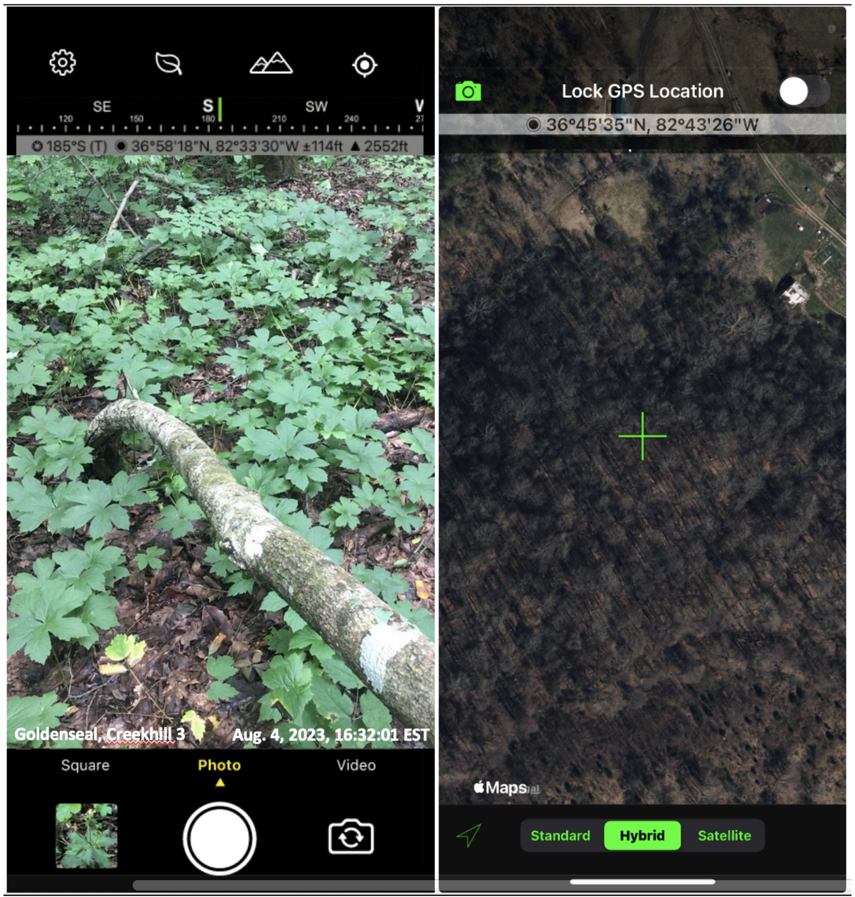

Figure 11. Example of a photo taken from the same location each year to assess change over time visually. The photo could be taken using a broader angle/view than what is depicted here. Notice how compass direction, GPS coordinates, and user-written notes are embedded in the photo on the left. Both photos were taken using the Solocator App. (For the purposes of these public instructions, GPS coordinates in these photos have been scrambled so as to not reveal the true location of the goldenseal depicted here). Panoramic videos can be taken from the same representative locations as well.

4. **Extrapolate numbers to the whole population.** Once data are collected from the previous three steps, the size/age category plot averages can be applied to the estimated DI percentages to extrapolate population size by using mathematical formulas that are embedded in an Excel spreadsheet created for this purpose (linked below). You will need to enter certain numbers obtained from the steps above into the spreadsheet (population area (step 1), data from the plot readings (step 2), and density intensity percentages (step 3), and it will automatically calculate the estimated Total Individuals in Population (TIP) and total individuals for each size/age category (Total Mature Reproducing (TMR), Total Mature Non-Reproducing (TMNR), Total Intermediate (TI), and

Total Young (TY). Figure 12 shows example output for a goldenseal case study applying these methods. These results can help inform decisions for responsible harvesting of these plants in this population. (For example, knowing that there is a very small percentage of reproducing individuals, you may choose not to harvest as many, knowing the population may not be replacing itself quickly. Furthermore, you may want to take more effort to collect and plant the resulting seeds.) If you want to understand the formulas behind it so you can adapt as necessary to different plant types and/or circumstances, see the Appendix, which explains the logic behind the calculations and provides definitions for the terms and acronyms. Click on the following link to download an Excel spreadsheet where you can enter your data to automatically calculate your results: Plant Population Data Analysis .xlsx

Size/Age Category	Estimated Total Indiviudals (TI) for Size/Age Categories
MR	722.3277409
MNR	9007.851827
I	2124.493355
Y	934.7770764

Total Populaiton Area (TPA) (m^2)	970
Estimated Total Individuals in Population (TIP)	12789.45

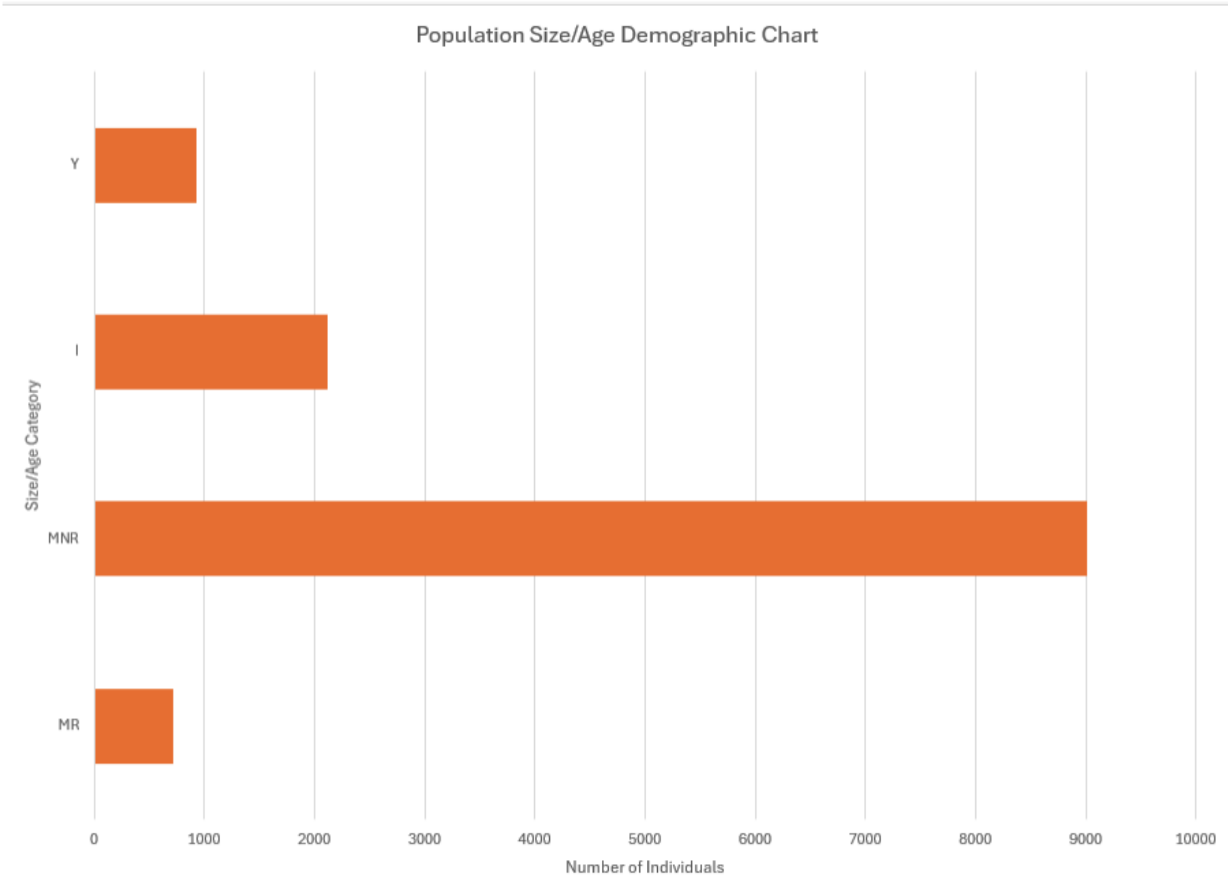

Figure 12. Example output and results of data collected on a goldenseal population using these methods.

Appendix. (Formulas used in the Excel spreadsheet Plant Population Data Analysis .xlsx).
*Note that below are the steps and mathematical equations used to extrapolate data about the entire local population of plants. However, for ease of use, it is recommended to follow the instructions in the Excel link above, which has the formulas already embedded into it. These formulas are provided below mainly for those who may want to change them to adapt to new methods for different types of plants and circumstances.

1. **Average up the varying size/age categories for each varying density intensity plot.**
   1.1. In step two, data was gathered about how many individuals for each size/age category were in each density intensity plot. There were three density intensity plots for each density intensity category.
      1.1.1. High-Density Intensity (HDI), Medium Density Intensity (MDI), Low-Density Intensity (LDI), and Very Low-Density Intensity (VLDI).
   1.2. To get the averages for each size/class category within each density intensity category, add up each plant for each size/class category within the separate density intensity categories. Then divide each sum by the number of plots present for each density intensity. This number should be three.
   1.3. Whenever the averages are gathered, there should be a total of sixteen values.
2. **How to get Density Intensity Averages (DI_{av}) for each Density Intensity (DI) category**
   2.1. Add up all of the plant averages for Mature-Reproducing (MR), Mature Non-reproducing (MNR), Intermediate (I), and Young (Y) to get the DI_{av} for the varying categories or rather to get the high DI_{av} (HDI_{av}), medium DI_{av} (MDI_{av}), low DI_{av} (LDI_{av}), and very low DI_{av} ($VLDI_{av}$).
   2.2. It is important to note that the plant averages described are the sums of the averages for the four different size/age categories for each DI category that were gathered from the circle plots described in step 2.4. This should result in a high-density intensity average (HDI_{av}), a medium-density intensity average (MDI_{av}), a low-density intensity average (LDI_{av}), and a very low-density intensity average ($VLDI_{av}$).
   2.3. Formulas:
      2.3.1. $HDI_{av} = MR_{HDI} + MNR_{HDI} + I_{HDI} + Y_{HDI}$
      2.3.2. $MDI_{av} = MR_{MDI} + MNR_{MDI} + I_{MDI} + Y_{MDI}$
      2.3.3. $LDI_{av} = MR_{LDI} + MNR_{LDI} + I_{LDI} + Y_{LDI}$
      2.3.4. $VLDI_{av} = MR_{VLDI} + MNR_{VLDI} + I_{VDLI} + Y_{VLDI}$

2.3.5. DI_{av}=MR + MNR + I + Y

3. How to get Density Intensity Ratio (DI_{ratio}):

3.1. Convert each Density Intensity Percentage (DIP) to a decimal form by dividing each DIP by 100.

3.1.1. It is important to note that the DIP values are the percentages that were assigned to each DI category when looking at the smaller area or population.

3.1.2. There will be a high DIP (HDIP), a medium DIP (MDIP), a low DIP (LDIP), and a very low DIP (VLDIP).

3.2. Multiply each DI_{av} by each DIP.

3.3. The product of DI_{av} and DIP for each DI category should result in four different Density Intensity Ratios (DI_{ratio}) of a high-density intensity ratio (HDI_{ratio}), a medium-density intensity ratio (MDI_{ratio}), a low-density intensity ratio (LDI_{ratio}), and a very low-density intensity ratio ($VLDI_{ratio}$).

3.4. Formulas:

3.4.1. HDI_{ratio}=HDIP*HDI_{av}

3.4.2. MDI_{ratio}=MDIP*MDI_{av}

3.4.3. LDI_{ratio}=LDIP*LDI_{av}

3.4.4. $VLDI_{ratio}$=VLDIP*$VLDI_{av}$

4. How to get Total Individuals in Population (TIP):

4.1. First one needs to get the Total Density Intensity Ratio (TDI_{ratio}) which is the sum of the HDI_{ratio}, the MDI_{ratio}, the LDI_{ratio}, and the $VLDI_{ratio}$.

4.2. Take the TDI_{ratio} and multiply it by the total population area (TPA).

4.2.1. Note that the TPA was gathered when walking around the total population using either a phone app that calculated it for you or by using measuring tapes in step 1.2.

4.2.2. The TPA, if not in meters, should be converted to meters.

4.3. The product of the TPA and the TDI_{ratio} is the total individuals in the population (TIP).

4.4. Formulas:

4.4.1. TDI_{ratio}= HDI_{ratio} + MDI_{ratio} + LDI_{ratio} + $VLDI_{ratio}$

4.4.2. TIP= TDI_{ratio} * TPA

5. How to get the averages for the size/age categories: mature reproducing average (MR_{av}), mature non-reproducing average (MNR_{av}), intermediate average (I_{av}), and young average (Y_{av}).

5.1. It is important to note that information for each size and age category number is calculated in step 2.5.

5.2. Add up all of the averages for each separate size/age class including MR. MNR, I, and Y.

5.3. This will get you the average for each size/age category ie. MR_{av}, MNR_{av}, I_{av}, and Y_{av}.

5.4. Formulas:

5.4.1. $MR_{av}=MR_{HDI}+MR_{MDI}+MR_{LDI}+MR_{VLDI}$

5.4.2. $MNR_{av}= MNR_{HDI}+MNR_{MDI}+MNR_{LDI}+MNR_{VLDI}$

5.4.3. $I_{av}= I_{HDI}+I_{MDI}+I_{LDI}+I_{VLDI}$

5.4.4. $Y_{av}=Y_{HDI}+Y_{MDI}+Y_{LDI}+Y_{VLDI}$

6. How to get the size/age category ratios: mature reproducing ratio (MR_{ratio}), mature non-reproducing ratio (MNR_{ratio}), intermediate ratio (I_{ratio}), and the young ratio (Y_{ratio}).

6.1. Add up MR_{av}, MNR_{av}, I_{av}, and Y_{av} to get the total size/age category average ($TSAC_{av}$).

6.2. Take each MR_{av}, MNR_{av}, I_{av}, and Y_{av}, and divide each of them by the $TSAC_{av}$ described above.

6.3. The quotients gathered from above are the different size/age category ratios (MR_{ratio} MNR_{ratio} I_{av} Y_{av}).

6.4. Formulas:

6.4.1. $TSAC_{av}= MR_{av}+MNR_{av}+I_{av}+Y_{av}$

6.4.2. $MR_{ratio}= MR_{av} / TSAC_{av}$

6.4.3. $MNR_{ratio}= MNR_{av} / TSAC_{av}$

6.4.4. $I_{ratio}= I_{av} / TSAC_{av}$

6.4.5. $Y_{ratio}= Y_{av} / TSAC_{av}$

7. How to get the total individuals for each size/age class.

7.1. Take MR_{ratio}, MNR_{ratio}, I_{ratio}, and Y_{ratio}, and multiply them all by the TIP.

7.2. The products of the MR_{ratio} and TIP will be the total mature reproducing, which is the estimated total number of mature reproducing plants (TMR) in the whole local population. This is also how the total number of mature non-reproducing plants (TMNR), total number of intermediate plants (TI), and the total number of young plants (TY) is gathered with respect to their various size/age categories.

7.3. Formulas:

7.3.1. $TMR = MR_{ratio} * TIP$

7.3.2. $TMNR = MNR_{ratio} * TIP$

7.3.3. $TI = I_{ratio} * TIP$

7.3.4. $TY = Y_{ratio} * TIP$

Glossary:

Note that these are the acronyms and their meanings that are used in Appendix A.

- Density Intensities (DI): The density intensity is the category of varying percentages of an area that is covered by the specific plant/fungi you are looking at.
    - **H**: DI High (60–100% cover)
    - **M**: DI Medium (25–60% cover)
    - **L**: DI Low (5–25% cover)
    - **VL**: DI Very Low (0–5% cover)
- Size/Age Categories
    - **MR**: Mature Reproducing
    - **MNR**: Mature Non-Reproducing
    - **I**: Intermediate
    - **Y**: Young
- Size/Age Classes within Density Intensities (DI):
    - $\mathbf{MR_{HDI}}$: Mature Reproducing within HDI plots
    - $\mathbf{MNR_{HDI}}$: Mature Non-Reproducing within HDI plots
    - $\mathbf{I_{HDI}}$: Intermediate within HDI plots
    - $\mathbf{Y_{HDI}}$: Young within HDI plots
    - $\mathbf{MR_{MDI}}$: Mature Reproducing within MDI plots
    - $\mathbf{MNR_{MDI}}$: Mature Non-Reproducing within MDI plots
    - $\mathbf{I_{MDI}}$: Intermediate within MDI plots
    - $\mathbf{Y_{MDI}}$: Young within MDI plots
    - $\mathbf{MR_{LDI}}$: Mature Reproducing within LDI plots
    - $\mathbf{MNR_{LDI}}$: Mature Non-Reproducing within LDI plots
    - $\mathbf{I_{LDI}}$: Intermediate within LDI plots
    - $\mathbf{Y_{LDI}}$: Young Within LDI plots
    - $\mathbf{MR_{VLDI}}$: Mature Reproducing within VLDI plots
    - $\mathbf{MNR_{VLDI}}$: Mature Non-Reproducing within VLDI plots
    - $\mathbf{I_{VLDI}}$: Intermediate within VLDI plots
    - $\mathbf{Y_{VLDI}}$: Young within VLDI plots
- Density Intensity Percentages (DIP): The percentages that are found in the subpopulation that can be applied to the whole population. They are used for the four different DI.
    - **HDIP**: High-Density Intensity Percentage
    - **MDIP**: Medium-Density Intensity Percentage
    - **LDIP**: Low-Density Intensity Percentage

- **VLDIP**: Very Low-Density Intensity Percentage

- T= Total
  - **TMR**: Total Mature Reproducing
  - **TMNR**: Total Mature Non-Reproducing
  - **TI:** Total Intermediate
  - **TY**: Total Young
  - **TIP**: Total Individuals in Population
  - **TPA**: Total Population Area
- Ratios
  - **MR_{ratio}**: The ratio of Mature Reproducing plants to the total number of plants recorded in the plots
  - **MNR_{ratio}**: The ratio of Mature Non-Reproducing plants to the total number of plants recorded in the plots
  - **I_{ratio}**: The ratio of Intermediate plants to the total number of plants recorded in the plots
  - **Y_{ratio}**: The ratio of Young plants to the total number of plants recorded in the plots
  - **HDI_{ratio}**: High-Density Intensity Ratio that is gathered by multiplying the High-Density Intensity Percentage (HDIP) by the HDI_{av}
  - **MDI_{ratio}**: Medium-Density Intensity Ratio that is gathered by multiplying the Medium-Density Intensity Percentage (MDIP) by the MDI_{av}
  - **LDI_{ratio}**: Low-Density Intensity Ratio that is gathered by multiplying the Low-Density Intensity Percentage (LDIP) by the LDI_{av}
  - **$VLDI_{ratio}$**: Very Low-Density Intensity Ratio that is gathered by multiplying the Very Low-Density Intensity Percentage (VLDIP) by the $VLDI_{av}$
  - **TDI_{ratio}**: The total or sum of HDI_{ratio} MDI_{ratio} LDI_{ratio} $VLDI_{ratio}$
- Averages
  - **HDI_{Av}**: The average number of total plants in the high DI (HDI) circle plots.
  - **MDI_{Av}**: The average number of total plants in the medium DI (MDI) circle plots.
  - **LDI_{Av}**: The average number of total plants in the low DI (LDI) circle plots.
  - **$VLDI_{Av}$**: The average number of total plants in the very low DI (VLDI) circle plots
  - **DI_{Av}**: The average number of total plants in a category of DI circle plots
  - **MR_{av}**: The sum of all of the average number of mature reproducing plants from the four density intensities, which was gathered from the circle plots and then averaged.
  - **MNR_{av}**: The sum of all of the average number of mature non-reproducing plants from the four density intensities, which was gathered from the circle plots and then averaged.

- **I_{av}**: The sum of all of the average number of intermediate plants from the four density intensities, which was gathered from the circle plots and then averaged.
- **Y_{av}**: The sum of all of the average number of young plants from the four density intensities, which was gathered from the circle plots and then averaged.
- **$TSAC_{av}$**: The total size/age category average that is gathered by adding up all of the averages for the size/age categories.