Research Note

Pictures are worth more than a thousand grams

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Abstract

Land managers, ecologists, and global change biologists need to accurately describe net primary production (NPP) of a landscape. Their ability to accurately and precisely detect annual change in plant biomass determines how to manage a landscape, accurately describe treatment effects from an experiment, or understand how carbon is being stored in that ecosystem. Current practices or methods are hard to scale either down from LIDAR or NDVI, or scale up from allometric volumes and destructive plant biomass harvesting. Our study uses close-range photogrammetry (CRP) to measure shrub volume by creating three-dimensional models. We use this method that was developed to quantify eroding hill slopes to more accurately and precisely measure shrub volume. We found that CRP shrub volumes are 4-20% of the allometric volume measurements, but both are highly correlated with measured plant biomass (allometry R^2=0.9933; CRP R^2=0.9997). These results provide a novel way to accurately and precisely monitor experimental plants without altering the current treatments by harvesting plant material using standard photographic equipment and software.

Key words: *Artemesia tridentata*; monitoring; sagebrush steppe; close-range photogrammetry

Introduction

Accurately measuring Net Primary Production (NPP) is essential for climate change studies and land management decisions. Theoretically, NPP is the gross primary production minus plant respiration [NPP = GPP – R_{plant}] – essentially the biomass available for heterotrophs (Osvaldo & Austin, 2000). Yet measuring NPP, whether directly or indirectly, remains a significant challenge in ecology (Baskerville, 1972; Tausch, 1989; Field *et al.*, 1995; Alvarenga *et al.*, 2013) and can be costly and time consuming or difficult to relate it to the appropriate scale. At the plot scale, where experimental work often focuses, this is exceedingly challenging because most methods require harvesting plant biomass and using complex logarithmic regressions to measure NPP (Baskerville, 1972; Tausch, 1989; Reiner *et al.*, 2010). Removing plant material from the experimental plot can alter treatment effects, thus creating an ecological equivalence to the Heisenberg uncertainty principle where the measurement of a parameter changes its property.

Net primary production is a necessary variable in many ecological studies and yet it is one of the most difficult measurements to make accurately. Methods for measuring NPP also vary depending on if ecosystems have high or low rates of aboveground tissue

turnover(Chapin III *et al.*, 2011). Examples of ecosystems with high rates of turnover are grasslands and shrublands where NPP is commonly measured by time intensive and destructive methods of harvesting the annual biomass, then coupling it with another method such as canopy capacitance, or the pin intercept method (Elzinga *et al.*, 1998; Osvaldo & Austin, 2000). While this works well for these ecosystems, it does not work for ecosystems with slow turnover like forests or woodlands where measuring Leaf Area Index (LAI) is more suitable (Gower *et al.*, 1999; Osvaldo & Austin, 2000). While these are the most common methods there are problems in that all of these methods require coupling them to destructive harvesting to get site and species specific algorithms to extrapolate to plot level.

Stochastic events or experiments make direct measuring of NPP difficult, because the plant communities change with these events and by harvesting plant material a researcher further changes the plant community. This is a huge concern when looking at experimental treatment. For this reason ecologists are looking to find the best methods to indirectly measure NPP. Numerous methods have come from remote sensing through its first use of measuring reflectance in red and near infrared (NIR) bands from advanced very high-resolution radiometer (AVHRR) instruments on NOAA platforms. However, these methods are limited by the timing of when the images were captured (Singh & Glenn, 2009) and the ability to scale down and track trends at community and population scales (Villa *et al.*, 2013). Lidar is another option of an indirect measuring method that accurately and precisely accounts for NPP (Olsoy *et al.*, 2014), however, it is expensive to acquire the data or a terrestrial scanning unit. With all of the technological

advances in optics and sensors accurately determining NPP through remote sensing and direct plot measurements should be possible without destructively harvesting plant biomass and not being expensive.

The United States Geological Survey has been pioneering a technique that tracks soil erosion through photogrammetry. This is not a new method but it shows promise to being able to non-destructively account for changes in canopy architecture or growth of plants at the population or community scales. Photogrammetry is based off of a camera taking pictures at a location from multiple different angles and then using a computer program or algorithm to stitch and overlay the images together to create a three-dimensional image. Through the use of sequential images, researchers can quantify how much change has occurred over time (Matthews, 2008). A subclass of photogrammetry that is used for measuring soil erosion is called close-range photogrammetry (CRP). This method takes a camera on a tripod and takes photographs from multiple angles to accurately measure soil loss from hill slopes (Matthews, 2008). Another use of CRP has been with creating topographic maps with remote sensing from aerially photographs. Because of the ability to use photogrammetry at various scales and settings this make it an attractive method for determining plant biomass non-destructively, which is fundamental in determining NPP in grasslands and shrublands.

Our study looked at how using close-range photogrammetry could be transferred from measuring soil erosion to measuring plants to accurately describe canopy volume, the fundamental measurement for determining NPP in shrublands. The questions we asked are

is it possible to measure sagebrush individuals using CRP and accurately determine the shrub's volume based from multiple images? How do measurements of NPP using the improved estimate of shrub volume compare to the estimates of NPP from using traditional methods of estimating volume (i.e. allometric volume and destructively harvested biomass)? Will the improved precision of CRP meet the goals of ecological researchers – to accurately measure treatment effects and preserve plant tissue for future sampling?

Methods

Site location and design

Our study site is located in Rush Valley (40° 05' 27"N, 112° 18' 18"W), in the Great Basin Desert, 80km southwest of Salt Lake City, Utah with an elevation of 1650m. Our study site is dominated by Wyoming sagebrush (*Artemesia tridentata var. wyomingensis*) with an understory of annual and perennial grasses and forbs. The area receives an average 250mm of precipitation per year (Station name = Vernon, Utah Climate Center) which makes it a semi-arid shrubland.

At the study site we chose four Wyoming sagebrush individuals that were representative of different morphological and size classes to more accurately determine the correlations between biomass, allometric volume, and close-range photogrammetric volume. Each shrub was tagged with a unique identification number for accurate recording throughout each sampling procedure.

Photogrammetry

Close range photogrammetry was accomplished with a Canon 50D DSLR on a camera tripod. There was no need to calibrate the camera or lens because of the computer based lens calibration program incorporated into the software from Agisoft (Agisoft LLC, St. Petersburg, Russia). Before photographing each shrub we placed a white drop cloth beneath the shrub to create a backdrop that would make processing the photographs easier. Also, on the drop cloth we placed multiple Agisoft detection markers spaced 35cm apart for post-processing measurements. Each shrub had two sets of a 360° series of photographs taken at a downward 45° angle. The first set of photographs were shot with an additional white backdrop besides the white ground cloth for

Figure 1. A) Final CRP model with texture to show replication of actual shrub. B) Photograph of actual shrub with white background.

ease of masking, and then the second set of photographs were taken without the white backdrop to create the actual model.

Images uploaded to Photoshop Lightroom 4 (Adobe Systems Inc.) for color contrast enhancement and to create the masks for the second set of photographs taken. The second set of photographs for each shrub were uploaded into Agisoft Photoscan and aligned to create a point cloud model by lining up the background images. Once aligned then we were able to isolate the shrub by applying the specific masking for each shrub respectively. After the point cloud was constrained by the mask, we created the three-dimensional model. From the three-dimensional model we filled-in any holes and overlaid the photographs to the model to check accuracy of the shrub to the original photograph (Figures 1.A & B). After the model was formed we detected the detection markers and set their lengths to be recognized through the software, which allowed us to calculate volume of the shrub model. These CRP and three-dimensional model procedures were repeated for each shrub.

Allometric calculations of volume

After each sagebrush individual was photographed, standard allometric volume measurements were taken to determine the volume of the shrub. The first measurement taken is the height of the shrub from where the soil meets the base of the shrub to the tallest vertical stem. Then we measured the widest portion of the shrub and then made a second measurement perpendicular to the previous measurement. Using these three measurements it is possible to calculate the volume of a shrub. The most commonly used geometric volume that gives the greatest

accuracy is an ellipsoid (Equation 1) (Murray & Jacobson, 1982; Reiner *et al.*, 2010).

$$Shrub\ Volume = \left(\frac{3.14159}{6}\right) * height * width_1 * width_2$$

Equation 1. Equation for determining sagebrush volume ellipsoidal geometry.

Wyoming sagebrush biomass

After the photographs were taken, and the allometric measurements were recorded we harvested the sagebrush to determine biomass. Each shrub was cut at soil level and stored in a box labelled with a unique identifying number. Then each shrub was placed in a drying oven and dried for 96 hours at a temperature of 60°C to remove all moisture from the plant tissue. Once dried and cooled we weighed each shrub to obtain its dry weight biomass in grams. This method is a standard protocol for determining plant biomass (Elzinga *et al.*, 1998; Osvaldo & Austin, 2000).

Results

Using close-range photogrammetry (CRP) in predicting sagebrush volume as a proxy for biomass was more accurate (R^2 = 0.9997) than using allometric volume measurements as a proxy for biomass (R^2 = 0.9933) (Figures 3.A, B, C), although this may be in part due to differing sample size. The percent difference range between CRP and allometric volumes is that the CRP measurements are 4% – 20% of the allometric volumes. Initially we measured four sagebrush individuals using CRP however the detection markers were not found on one individual so the CRP volume could not be determined for that individual.

$y = 0.0053x - 30.806$
$R^2 = 0.9933$

A

$y = 4.5201x + 5838$
$R^2 = 0.9997$

B

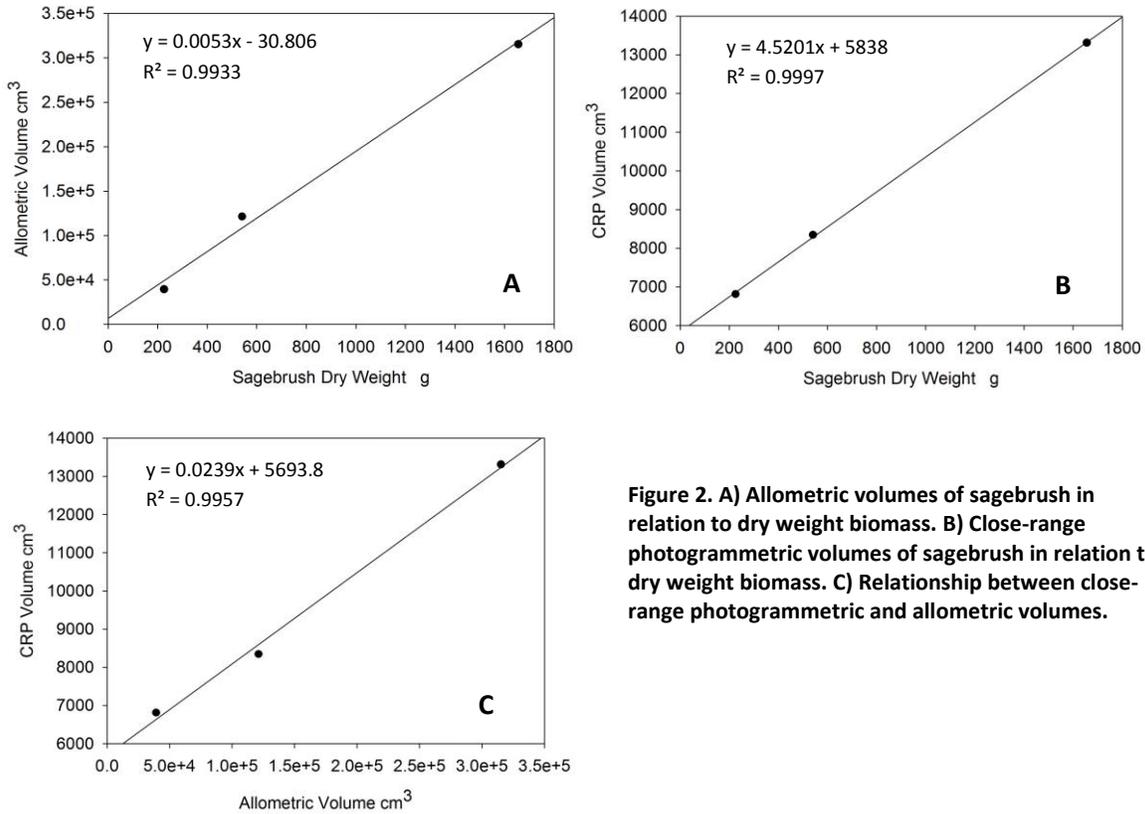$y = 0.0239x + 5693.8$
$R^2 = 0.9957$

C

Figure 2. A) Allometric volumes of sagebrush in relation to dry weight biomass. B) Close-range photogrammetric volumes of sagebrush in relation to dry weight biomass. C) Relationship between close-range photogrammetric and allometric volumes.

Discussion

Our results indicate that CRP is a promising technique to rapidly and accurately acquire sagebrush volume and estimate biomass. We understand that a sample size of three does not show the true variation in unexplainable errors but when compared to the same three individuals for allometric measurements we still saw a potential improvement in the R^2 values. Both allometric and CRP methods correlate well by explaining variations in volume to biomass. The significant difference is in how much less volume there is between the allometric and CRP methods. Allometric volume relationships assume that the density of leaves and branches are invariant. This assumption allows for a simple ellipsoid model to describe biomass; however shrub architectures are different by site and between species. The CRP volume method allows for these differences, thus there is no need to create allometric equations by site or on species specific basis.

Currently we take 20 – 30 photographs per shrub and we are determining how many photographs are necessary to eliminate the time required in the field and for full processing. Other research in this field has shown that eight photographs give good resolution for three-dimensional model building of an object (Postma *et al.*, 2013). This resolution is crucially important to accurately determine biomass. Using allometric measurements requires overestimating the volume of the shrub which when scaling up to landscapes makes the extrapolation highly variable. As of right now we are still working on how to properly scale our close-range photogrammetry

method up but it will have much less variation than using allometry.

Researcher Implications

CRP is an ideal technique that could eliminate the need for harvesting or developing site and species specific allometric equations. The ability to quickly and accurately measure shrub biomass allows researchers the ability to make more precise and accurate measurements during experiments. It is also very cost effective because all it requires is a camera and the Agisoft Photoscan software. The ability to teach and/or learn the program does not require much time. Another benefit to researchers is that an archive of photographs can be compiled to make additional time series measurements to track changes over time of the shrub. Because the software is able to create models based off of the photographs and detection markers this method could be applied to numerous other perennial plant species to monitor and calculate biomass without destructively harvesting in experimental or sensitive sites.

Acknowledgements

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