Mapping Forest Structure – Trunks and Logs – with AI
Conceptual Draft

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Older forests are often of higher conservation value, both for the biodiversity that they support and for their aesthetic appeal. As forests age, not only do trees grow larger, but various disturbances cause variation within the forest, such as when individual trees die and are replaced by younger ones in the gap left behind. The dead old trees become logs, which are important for wildlife habitat and ecosystem dynamics. Thus, tree size and spacing, as well as the presence of Coarse Woody Debris (e.g. lots of big logs), are important indicators of old forest, with critical conservation implications. Specifically, old forests generally contain:

- Trees with larger trunks
- Trees with more variability (e.g. Standard Deviation) in trunk size
- Trees that are spaced further apart from each other
- Trees with more variability in spacing
- Lots of large scattered dead wood

As a conservation biologist, when I am trying to understand a forest, I typically scan through winter aerial and satellite imagery to look at the above features by eye, in a somewhat subjective manner. However, this is time-intensive, especially if I were to try to develop objective ways to quantify these observations over large areas. The goal of this project is to train a computer to do this task. One of the questions on my mind is how objectively quantifiable these metrics really are from aerial images – the places I know to be old growth I know from ground investigations, and so I am biased when I look subjectively from above. So, can this really be done given the available data?

A brief literature review (below) shows that there has been a fair amount of work on using satellite imagery to identify tree crowns, but not as much work on looking at trunks and downed wood – although, to be clear, I have not done an extensive literature search, so I may very well have missed important studies. In part, the lack of focus on trunks and downed wood may be because many of the study areas are covered by coniferous forests.

Throughout much of the southeastern US, the forest is largely dominated by deciduous trees, which allows satellite and aerial imagery to see into the forest during winter. This includes Nashville, where our organization, Radnor to River, works (read our recent Year End Reports to learn about us here: https://radnor2river.org/resources/). Nashville has approximately 225 square miles of forest, and we are focused on identifying, protecting, and creating connecting corridors through these forests. Last year, we created a map of forests and invasive species across the county (look under "Maps" at the link above). We work with other NGOs and the local government, which hosts on its GIS portal high-resolution aerial winter imagery for the entire county from every year or two (https://maps.nashville.gov/ParcelViewer/).

The first goal would be to run an analysis for Nashville using the high-quality data which the city has. Ultimately, it would be great to make raster maps of forest structure for the entire southeast deciduous forest based on other available data, which contain metrics that correspond to the list above such as:

- Mean Trunk Diameter
- Trunk Standard Deviation
- Mean Tree Spacing
- Tree Spacing Standard Deviation
- Mean Dead Wood Diameter
- Dead Wood Volume

However, any single one of those metrics could be really useful on its own. Perhaps the easiest and most interesting to focus on first would be the Dead Wood metrics. When you look at a winter image of a forest (see screenshots of example frames that follow), there are basically major three sets of dark lines that we want to identify:

- Trunks – appear as parallel lines unless the airplane is directly overhead,
- Trunk Shadows – appear as parallel lines often at a different angle than the trunks, depending on the time of day
- Downed Wood – appear usually as short scattered line segments that have no particular direction (they're not parallel to the other things above)

These need to be discriminated from the pattern of canopy branches visible in the images. I envision a script that could identify the one or two dominant directions of the major parallel lines (trunks & shadows) in each frame, and then based on those identify the downed wood and calculate the thickness and density of the downed wood and trunk/shadow lines. The ability to see these features are affected by the angle of the flyover (airplane or satellite), the topographic slope, which can extend or shorten shadows and/or make them difficult to see (we can account in part for this with other layers), the time of day (which we may be able to tell by the shadow angle), the tree species (some hold leaves more in winter), the season (most of the initial images are mid-winter, but for other regions they are late spring, etc), the image quality (especially for areas outside of Nashville), and other factors.

If we had an AI script to handle some of the difficult recognition tasks – ideally that we could call directly from R (the language I know best) and/or Python – we could write container scripts to loop through imagery and call the code for specific frames. We'd have to think about the data input/output types and scale of operation. I believe the output from the R package for crown delineation (Dalponte 2018) are vector-based data with circles around each individual crown – although, I haven't yet actually played with this package. Ultimately, I want to get to raster-based data which summarizes metrics within grid cells. It may be that larger frames are needed to identify overall forest patterns, but then metrics could be generated for smaller grid cells (30m?) within these frames. It gets complicated, particularly near edges, as forest structure can change dramatically from one side of a frame to another, and sometimes roads or forest edges cut through the frames. Using other GIS products, we can filter out areas of non-forest, or areas of evergreen forest, or include in the input data information on percent tree canopy within 30-m pixels (e.g. the NLCD database layers; https://www.mrlc.gov/data), road and building locations, etc. Having multiple years of data is really helpful, because the angles of the plane and sun are often different in the different years.

In the next few pages, I've provided some screenshots of example frames where you can pick out trunks, shadows, and logs, including some of the challenges in the data.

Literature

Braga, J. R., Peripato, V., Dalagnol, R., Ferreira, M. P., Tarabalka, Y., Aragão, L. E., ... & Wagner, F. H. (2020). Tree Crown Delineation Algorithm Based on a Convolutional Neural Network. *Remote Sensing*, *12*(8), 1288.

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Wang, L., Gong, P., & Biging, G. S. (2004). Individual tree-crown delineation and treetop detection in high-spatial-resolution aerial imagery. *Photogrammetric Engineering & Remote Sensing*, *70*(3), 351-357.

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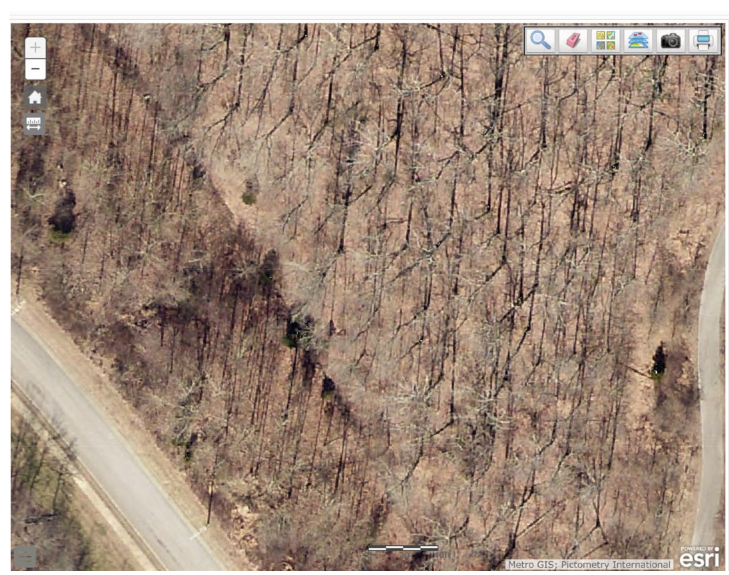
These are screenshots I casually grabbed from Nashville's GIS portal. The frames are about 125m wide and 100m tall – the NLCD forest layers have 30m pixels, so it may or may not make sense to think about parts of the analysis if the frames are broken into 12 or so grid cells.

This frame is an old growth forest with wide (but relatively short) trees spaced far apart and several large downed trees. This is a hilltop, and on the top of the frame (N slope), trunks point NE, while on the bottom (S slope), trunks point SE. Shadows are generally pointing N.

In the top and right of this frame is a mature forest, but not too old - as trees are smaller and closer together than the frame above. No visible logs. Trunk direction and shadow direction both appear to be N/NE, small angle between then.

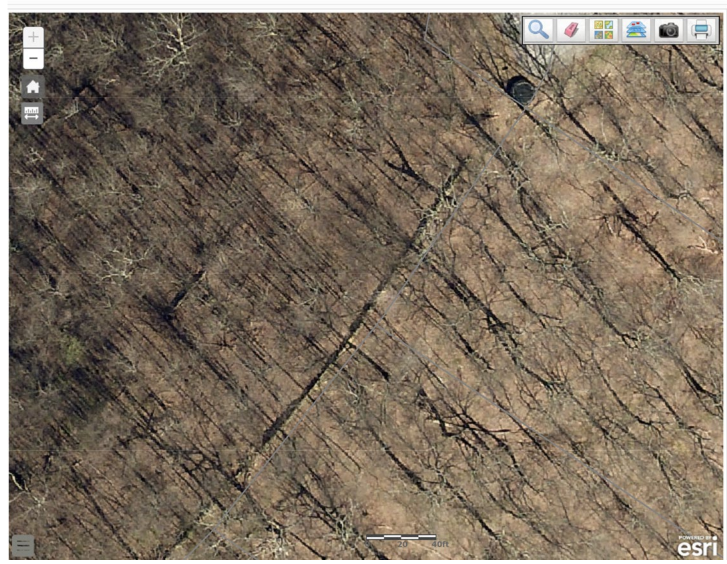
On the right is a mature forest, but near the road on the left the forest is very young with many small trees. No logs visible. Trunk direction is SW, shadow direction is N.



Some Other Challenges

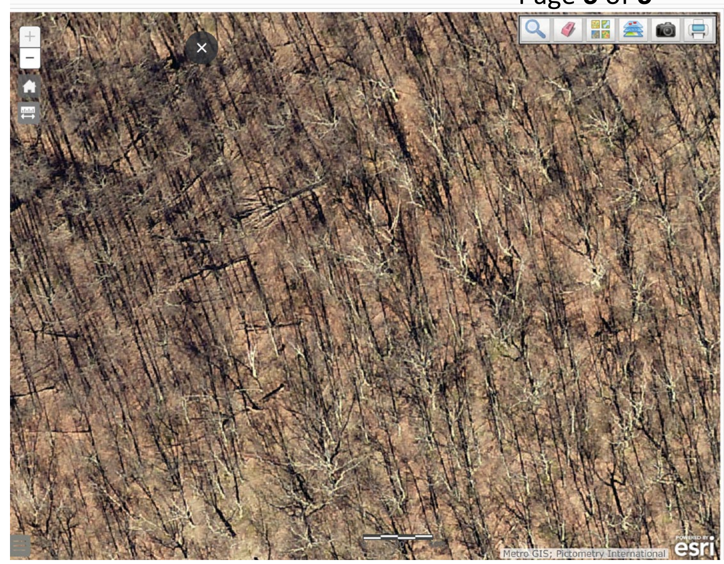
Here, images from two different aerial flyovers are stitched together – as evident where the shadow directions change.

Here, a stone wall cuts through the forest, and the forest structure appears to change from older in the SE to younger in the NW. However, it is possible that the hillslope needs to be taken into account in understanding the shadows, as the wall runs along a ridgeline.



On this very steep north-facing slope, it is difficult to pick out individual shadows, which are extended, faint, and obscured by canopy. I believe there is also a gap from a landslide at the top of the image.

These are all the same frame (same as first one in previous page) from different years, and combining these can help pick out logs etc, several of which are visible in the frames. Note the older images are lower quality.



These logs are clear in some but not all frames