Appendix: Field protocol for digital tree mapping

Overview
This document is a field protocol for digital field mapping of individual tree crowns in high resolution remote sensing digital images. The protocol relies on the use of 1) location information from a GPS receiver, and experience in 2) survey techniques and 3) image interpretation. The GPS signal is used as reference and bearing to a known location in the image, survey techniques are used to locate the approximate location and size of a tree crown, and image interpretation is to identify the exact location and approximate edges of the crown. While the three components of digital field mapping (GPS signal, survey techniques, and image interpretation) are presented in isolation here, they will most often by used synchronously during the process of mapping a single tree crown.

Task	Time	Output
Field mapping	6 hours	Spatial polygons of 20 individual tree crowns (ITCs). The number of crowns will vary by forest condition and travel time between trees and sampling locations.

Personnel
The protocol is most efficient with two people; one person as the lead mapper and the other person taking measurements and recording data. The equipment and description of steps is written for two people, but one person can complete the same protocol at a slower pace.

Field equipment
See Figure 2 and Table 1 of main text for full description of equipment.
- Tablet computer with protective case and strap
- Consumer-grade GPS receiver unit
- Compass
- Rangefinder/measuring tape
- Field notebook

Process
The following is organized into three main steps These steps should be done in order when initially learning the process but can be done with more flexibility once the technicians have experience and are comfortable with the process.

<u>Using the GPS location as a reference</u>

The GPS signal is initially helpful in establishing a reference point where your physical location is identified in the image.

1. In an open area, turn on your GPS and give it time to get a lock on the satellites. This could take a few minutes.
2. Once nearby your mapping location or plot, identify distinguishable features in image or location with good GPS signal. The best areas or features to use as a reference point are large trees on the edge of a forest or roadway, dead trees, or large canopy gaps. These areas will allow for better GPS reception because of a more open canopy and are visually distinct in the image.
3. Use this location as reference point for mapping near your area because it will help you get your bearings and sense of direction when relating imagery to ground view. Stay at this reference location until the GPS location matches where you are in the image. The location may drift but should center around your position.

<u>Surveying techniques</u>

The location of individual tree crowns can be identified using a combination GPS navigation and surveying techniques rather than relying solely on the GPS signal to determine the exact location.

1. From the reference location, identify a tree to be mapped on the ground. It is best to start with large trees nearby the reference location.
2. With a partner, use a measuring tape to measure the distance between the reference location and the center of the tree crown. If working alone, a laser range finder can also be used to measure the distance to the stem of the tree but note that the tree stem may not be directly under the crown.
3. With a compass, measure the direction to the target tree from the reference point.
4. With the distance and direction from the reference point to the center of the target tree canopy measured, the approximate location of the tree in the image can be determined and marked with a point. Many GIS software systems have a built-in measurement tool that can be used. Additionally, compasses with a clear, transparent housing can be placed on the tablet screen to identify the direction in the image.
5. To further help in identifying the tree in the image, measure the size of the crown, and if irregular in shape, measure the length of the longest diameter and note the angle. Use these measurements to help identify the tree crown in the image by looking at groups of pixels that match the size and orientation that you measured on the ground.

6. Once the approximate location and groupings of pixels associated with the tree crown have been located in the image, create a point for the center of the tree in the GIS application. Then use image interpretation skills to identify the pixels associated with the tree. These are discussed in the next section.

Image interpretation and crown mapping
Identifying the pixels associated with individual tree crowns requires skills in image interpretation.
1. Look for groupings of pixels that are similar in color in the spectral data. A canopy height model (CHM) or high-resolute color photos can also be used to identify a crown in the image.
2. Identify crown objects based on patterns of tree shadows on the ground and gradients of light within crowns. When working in an open area, shadows cast by the tree crown are often noticeable and fall consistently on one side of the trees based on the location of the sun. For closed-canopy forests, shadows cast by trees may obscure tree crowns in the image that may seem obvious on the ground. In addition, tree crowns will often have a brighter side and a darker side caused by the location and angle of the sun based on the time day the images were taken.
    a. Notice shadows case by tree crowns in the image.
    b. Note on the ground where the sun would be in the sky when the image was taken.
    c. Large trees that are above the rest of the canopy will be obvious in the image because they will be well illuminated and often cast a shadow on the ground or the rest of the canopy.
    d. Short trees, especially in a closed-canopy forest, will be harder to map because they may be potentially in the shadow of other trees.
3. Use your measurements of the shape and size of the tree to identify the tree crown. Note if there are any branches that jut out horizontally or vertically from the main canopy.
4. Physically walk the perimeter of the crown while following along visually with image/GPS on the tablet to confirm ground location of crown matches with image. It is best to walk around the tree several times to reduce GPS location errors. You may need to walk slowly as the GPS can be slow to catch up to your current position.
5. If the crown on the image is confirmed as the crown you physically circled, you can create a polygon on the image using the GIS software installed on the tablet.
    a. Polygons should be labeled with a unique tree identification number or code. This code should also be recorded in a notebook, along with other data collected about the individual.

6. In a notebook, record notes about each crown that you have mapped in the image, using the unique tree ID number or code to match to the polygon in the GIS application.
    a. We suggest keeping to a minimum the tabular data entered in tablet GIS in the field to avoid data loss and errors with auto-corrected text.
    b. In the field, estimating the edges of the crown is the most important task. Informative notes that would be helpful for lab digitization of each crown are especially helpful, includes notes about nearby species or boundaries that are hard to define.
    c. A level of confidence can also be noted while in the field. We recommend three categories that indicate how well the canopy center and canopy edges are captured.
        i. High = crown center and most pixels are captured in the polygon
        ii. Medium = crown center is not in the center of the polygon, but polygon includes some pixels that belong to the crown
        iii. Low = crown center is not captured in the polygon, and the polygon may not include pixels that belong in the crown. These low confidence crowns can be carefully examined in the lab and potentially revisited in the field.
7. Proceed to mapping additional crowns by looking for next distinct crown in the image. Knowing the distance that each pixel represents, combined with knowing a general direction to proceed (North, South, etc....), you can use a range finder to measure distance and compass direction on the ground to give you a heading for the next crown.
8. Once at the next potential crown, repeat the process until plot is mapped as fully as possible.
9. At the end of each day, data from the GIS application should be exported and loaded onto a computer for digitization.
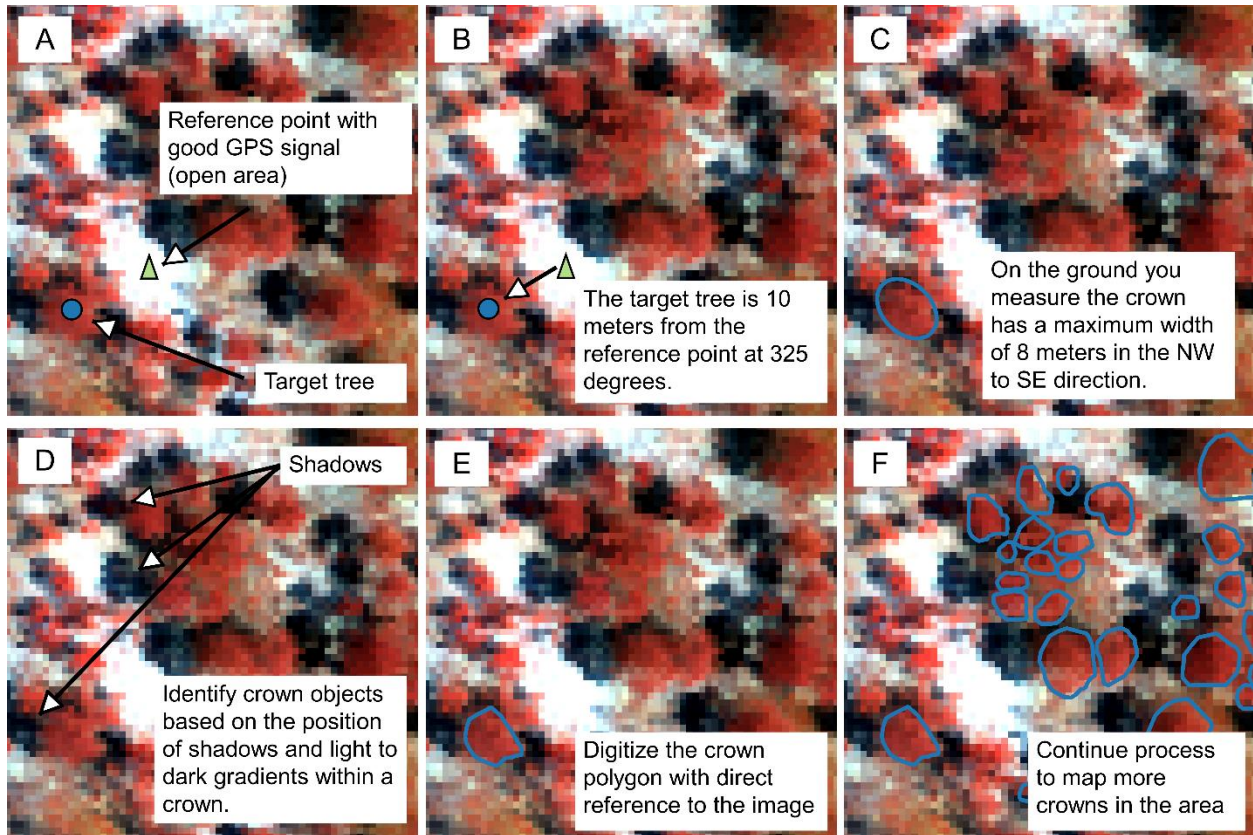
Summary of field mapping process. A) Identify a reference point where there is a good GPS signal and a visible feature in the image (such as a large open area) nearby at target tree to map. B) Measure the distance and angle between the reference point and target tree. C) Measure the orientation and size of the largest width of the crown. D) Identify crown objects in the image based on shadows on the ground, gradients of brightness within the crowns, and variation in pixel color. Use what you see in the field as a guide for interpreting the image. E) Digitize the crown polygon shape. F) Repeat the mapping process for other crowns in the area.