The Urban Forest Effects (UFORE) Model: Field Data Collection Manual

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1. Introduction[1]

The Urban Forest Effects (UFORE) computer model was developed to help managers and researchers quantify urban forest structure and functions based on standard inputs of field, meteorological and pollution data[2]. The model currently calculates the following parameters based on local measurements:

- urban forest structure [e.g., species composition, tree cover; tree density, tree health (crown deterioration; tree damage), leaf area, leaf biomass; information on shrubs and ground cover types];
- hourly urban forest volatile organic compound emissions (emissions that contribute to ozone formation);
- hourly pollution removal by the urban forest and associated percent improvement in air quality; (for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter less than 10 microns);
- effect of trees on building energy use and carbon dioxide emissions;
- relative ranking of species effects on air quality;
- total carbon stored and net carbon sequestered annually by urban trees;
- insect and disease potential for gypsy moth and Asian longhorned beetle;
- pollen allergy rating for the species composition;
- exotic species composition; and
- tree transpiration

Data that UFORE analyzes can be based on a sample of an area (e.g., an entire city or neighborhood) or can be based on an inventory of trees (e.g. street trees). Model outputs are given for the entire population and individual trees measured.

As UFORE programming is modular, addition modules can and are being developed. Data collection for UFORE is designed to be relatively low cost, with much of the data already available from various sources (e.g., National Climatic Data Center, U.S. Environmental Protection Agency). Field data collection can be expanded or reduced based on the needs of the user. The purpose of this publication is to explain to UFORE users how to select samples; collect field data, and enter field data into a computer such that UFORE can analyze the data.

Until the new Windows® PC version is made available that will allow users to analyze and graph their own data, the Forest Service Northeastern Research Station in Syracuse, NY will analyze data that are transmitted to them in proper format (explained later in manual) and will mail back the UFORE results to the user. To schedule and discuss a UFORE analysis, please contact David J. Nowak at dnowak@fs.fed.us.

For more information on this model see www.fs.fed.us/ne/syracuse

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[1] Please note this manual was developed to aid in understanding data collection procedures. If there is anything you do not understand or if you have any further questions, please contact David J. Nowak at dnowak@fs.fed.us

[2] Nowak, D.J., and D.E. Crane. 2000. The Urban Forest Effects (UFORE) Model: quantifying urban forest structure and functions. In: M. Hansen and T. Burk [eds.], Proceedings: *Integrated tools for natural resources inventories in the 21st century*. IUFRO Conference, 16-20 August 1998, Boise, ID. General Technical Report NC-212, U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN. pp. 714-720.

2. UFORE Data Requirements

The UFORE program requires various data inputs depending on the type of analysis. Typically, the user will only have to collect field data.

Field Data – required for all analyses. Data collection can be based on a random sample of fixed area plots or an inventory of trees. The types of variables collected can vary, but certain core variables are required (e.g., species, DBH).

Meteorological data – hourly weather data are necessary to analyze:

- volatile organic compound emissions
- air pollution removal by the urban forest
- relative ranking of species' effects on air quality
- tree transpiration

These data are available for most cities around the world for the year 2000 at the U.S. Forest Service office in Syracuse, so users do not need to obtain these data.

Air pollution concentration data – hourly pollution concentration data are required to analyze:

- air pollution removal by the urban forest
- relative ranking of species effects on air quality

These data are available for many cities in the United States for 2000 at the U.S. Forest Service office in Syracuse, so users do not need to obtain these data. However, for cities outside of the United States or for years other than 2000, users will need to obtain hourly pollution concentration data (see Section 4.E.5).

Boundary layer height measurements – twice daily sounding measurements are needed to calculate percent air quality improvement due to pollution removal.

These data are available at the Forest Service office in Syracuse for select U.S. areas for 2000. Twice daily sounding measurements, if needed, can be obtained from the NOAA at a cost of about $175 for ten years of data.

3. UFORE Setup

To perform a UFORE analysis, five steps must be completed:

Step 1: Determine study area
Step 2: Decide what data need to be collected (i.e., what do you want to know about your urban forest?)
Step 3: Choose if data are to be collected on all trees (inventory) or a sample of trees
Step 4: Locate field plots (if sampling is conducted)
Step 5: Collect field data
Step 6: Analyze field data

Step 1: Determining the study area

The first question that must be answered is "What are the limits of the study area?" Is the analysis for a neighborhood, a street tree population, an entire city, etc.? The boundaries of the study area must be determined prior to analysis.

Step 1a: Is the study area stratified into smaller units?

For some studies, stratifying the study area into smaller units can aid in understanding the variation and differences within the study area. For example, the city area may be stratified (sub-divided) into land use classes or neighborhoods. If the study area is to be stratified, the boundaries of these strata need to be known prior to field measurements.

Step 2: Determining data collection needs

There are many variables that can be collected in the field and each variable collected add to the cost of the project. Thus, deciding which variables to collect is an important decision. The following is a list of data types that can be collected. For each data type, a decision must be made if these data are important for the analysis.

Long Term Data:
Permanent reference data (see sections 4.A and 4.C.4) are collected so that future data can be collected to assess changes.

Ground Cover Types:
Ground cover data (see section 4.C.2) are used to estimate the amount and distribution of various ground cover types in the study area.

Shrub data:
Shrub data (see section 4.C.3) are used to estimate pollution removal and VOC emissions by shrubs.

Tree Data:
The following are the core variables that are required and used in most UFORE analyses (parenthesis list if data are used for structural (S) or functional analyses [air pollution removal (A), carbon storage/sequestration (C), VOC emissions (V), energy conservation (E), pollen index (P)]):

- Tree species (all)
- Dbh (S, C)
- Height to base of live crown (S, A, V, P)
- Total tree height (all)
- Crown width (S, A, V, P)
- Crown light exposure (S, C)

- Percent canopy missing (S, A, V, P)
- Crown dieback (S, C, E)
- Distance and direction to nearby building (E)

See section 4.C.4 for more details

Step 3: Data collection type

If data are to be collected on all trees (e.g., all streets in an area), then data collection is considered an inventory. Inventories are particularly useful for management information on individual trees and for small tree populations. However, if general information is needed on a large tree population (e.g., entire city), then sampling of only a small portion of the total tree population is needed. With sampling, the total estimates will have some bound of uncertainty (standard errors) based on the sample size. With inventories, many estimates are exact as all tree have been inventoried. Thus, a decision must be made as to whether an inventory or sample will be conducted.

Step 4: Locating field plots

If sampling is chosen as the data collection type, then field plots need to be randomly selected for sampling of field data. If the sample area is stratified (Step 1a), then plots are randomly distributed within each stratum, otherwise plots are randomly distributed throughout the entire study area. Prior to locating field plots, the number of plots to be sampled needs to be determined. As the number of plots increases, the standard error decreases and the more confident one is in the estimate for the population. However, as number of plots increases, so does the cost of field data collection.

As a general rule, 200 plots (1/10 acre) in a stratified random sample in a city will yield a standard error of about 10% for an estimate for the entire city (e.g., number of trees in the city). With the first 100 plots, the standard error drops more rapidly than with the second 100 plots, but standard error drops with increased sample size. A crew of two people can typically measure 200 plots within one summer for a city with about 20% tree cover. Actual number of plots measured varies based on many factors, including size of city (increased drive time between plots) and tree cover (the more trees in a city, the more time is spent measuring trees).

If stratification is used, it is recommended that at least 10 plots be put within each stratum. Land use maps are useful for stratifying the area into smaller units. Typically, for city analyses, the city area is divided into 5-10 stratum (land use types) so that results can also be reported for each stratum. Stratification of land into fairly homogenous units also tends to reduce variance of the estimates and lead to more precise results. If stratification is not done (e.g., in a small area analysis), results are reported only for the entire study area.

With stratification, the land uses with the most tree cover (e.g., residential areas, vacant and parks in forested regions) should receive the most plots so that field crews can collect as much tree data as possible. Plot distribution among strata proportional to the amount of tree cover is one way to help distribute the sample. Information on average tree cover for various land use types can be obtained from Table 1.

Due to problems in accessing plots (owner/occupant is not home or does not grant permission to enter the property) select at least 10% more plots in each land use stratum. A minimum of 10 extra plots per land use is a good rule to follow.

Table 1. Mean percent tree cover by land use and standard error (SE) for U.S. cities in different potential natural vegetation (PNV) types (from Nowak, D.J., R.A. Rowntree, E.G. McPherson, S.M. Sisinni, E. Kerkmann and J.C. Stevens. 1996. Measuring and analyzing urban tree cover. *Lands. Urban Plann.* 36:49-57.

	Forest PNV		Grassland PNV		Desert PNV	
Land use	Mean	SE	Mean	SE	Mean	SE
Park	47.6	5.9	27.4	2.1	11.3	3.5
Vacant/wildland	44.5	7.4	11.0	2.5	0.8	1.9
Residential	31.4	2.4	18.7	1.5	17.2	3.5
Institutional	19.9	1.9	9.1	1.2	6.7	2.0
Other[1]	7.7	1.2	7.1	1.9	3.0	1.3
Commercial/industrial	7.2	1.0	4.8	0.6	7.6	1.8

[1]Includes agriculture, orchards, transportation (e.g., freeways, airports, shipyards), and miscellaneous.

Once the number of plots in each stratum is determined, plots can be easily located within each stratum using a GIS tool (see http://www.fs.fed.us/ne/syracuse/Tools/tools.htm) if digital data are available on study area boundary, land use boundaries, and digital aerial photographs. Digital Orthophoto Quadrangles can be procured at http://earthexplorer.usgs.gov and National Land cover maps can be found at http://landcover.usgs.gov/natllandcover.html. If digital photos are not available, the GIS tool can still be used to locate plots on the land use or digital road map. If digital data are not available, paper maps of land use and hard copy photos can be used to locate plots using a random number generator and grid overlays on the map. Once plot locations are determined on the map, these locations should be transferred to aerial photographs to aid field crews in determining plot center. Various plot sizes can be used. Previous analyses have used 1/10 acre circular plots.

Plot size	Plot radius
1/75 ac	13.6 ft
1/24 ac	24.0 ft
1/10 ac	37.2 ft
1/6 ac	48.1 ft

Step 5: Collecting field data

Much of the remainder of this manual details field data collection and data entry procedures for analysis by the UFORE model

Step 6: Analyzing field data

The current version of UFORE is coded in SAS® Software. A Windows® PC version is in development and scheduled for limited test release in 2004. Prior to full conversion and public release of the Windows® UFORE version, data analyses will be performed by the USDA Forest Service in Syracuse, NY. To have an analysis conducted, contact David Nowak at dnowak@fs.fed.us. Four data sheets (in Excel or select other formats) will need to be constructed and sent for analysis (see section 4.D)

Summary

Before beginning data collection, the following questions must be answered (questions 3-4 pertain only if sampling conducted):

1. Is data collection an inventory or sample? Inventory Sample
2. Is data collection long-term (i.e., are the data to be remeasured in the future)? Yes No
3. Are data to be collected on ground cover types? Yes No
4. Are data to be collected on shrubs? Yes No
5. For trees, are data to be collected for analysis of:
    a) forest structure
    b) air pollution removal
    c) carbon storage / sequestration
    d) volatile organic compound emissions
    e) building energy effects

The following data are needed if sampling an urban forest (city, neighborhood, etc):

1. Study area boundary (map)
2. Study area size: _____ (acres or hectares)
3. Boundaries of individual strata (e.g., land uses) (map)
4. Name and size of each stratum (number of stratum is up to user):

	Name	Size (ac or ha)
1)		
2)		
3)		
4)		
5)		
6)		
7)		

5. Total number of plots to be sampled: _____
6. Number of plots per stratum (should equal total in #5; stratum should be the same as identified in #4):

	Stratum Name	Number of plots
1)		
2)		
3)		
4)		
5)		
6)		
7)		

4. Field Data Collection

A. Plot Establishment

Methods given are based on a 1/10 acre, circular, permanent plot.

1) Locate plot center in field from plot location given on aerial photograph and/or map.
2) Get permission to access property (if necessary, e.g., from resident).
   - if unable to access plot, select the first plot from the list of additional plots for that land use. Do not skip around; go in sequence.
3) At plot center, establish references to permanent fixtures (direction and distance from object) and GPS coordinates if GPS is available. On field data sheet, identify location (e.g., address if available, front or back yard, etc.). If plot is the middle of the forest, write specific directions (distance and direction) to relocate plot center. At the plot, record two witness trees and mark direction and distance from witness trees to plot center. Try to select unique species or DBH with respect to other trees on the plot.
4) Determine plot boundaries. Plot radius is 37.2 ft. If on slope, measure slope with clinometer and adjust plot width accordingly. Adjusted plot width, or limiting distance, can be read from the following table:

Slope %	5	10	12	15	17	20	22	25	27	30
Slope Angle	2.9°	5.7°	6.8°	8.5°	9.7°	11.3°	12.4°	14.0°	15.1°	16.7°
Limiting Distance 1/6 ac	48.2’	48.3’	48.4’	48.6’	48.8’	49.1’	49.3’	49.6’	49.8’	50.2’
Limiting Distance 1/10ac	37.2’	37.4’	37.5’	37.6’	37.7’	37.9’	38.1’	38.3’	38.5’	38.8’

5) If plot center falls on a building or other surface where the center point cannot be accessed, the plot is not to be moved. Distance to plot center from the edge of the obstruction should be measured from the aerial photograph. The boundary of the plot should be determined on the ground in the plot area that is not obstructed (Appendix A).

B. Shrub Vs. Tree

Any species that is classified as a tree or both (Tree and shrub)(PDF Species List) with a DBH ≥ 1 inch is considered to be a tree, for measurement purposes. If DBH of tree species does not equal one-inch, then the plant is considered a shrub. If woody plant does not reach 12 inches in height, then that plant is considered a herbaceous cover. Any species that is classified (PDF Species List) solely as a shrub can never be considered at tree, no matter how large the DBH.

C. Data Collection (See Appendix C for data collection forms)

*** = required variable for UFORE**
**** = required variable for permanent plots**
***** = required variable for water quality and quantity information (model in development)**

1. Plot Information (record only once per plot)

- **Plot ID*** - plot number from the aerial photograph (must be a unique identifier)
- **Plot address**** – additional notes will be useful if plot is located in area where there are no street numbers (vacant land, parks, industrial areas, etc.)
- **Land Use from map* –** predetermined land use from map. May be different from actual land use in the field as determined by crew.

- **Date**
- **Crew –** list first and last initials of each crew member
- **GPS coor** - coordinates of global positioning system at plot center (used for permanent plots if using a GPS)
- **Photo #** - roll number and picture number (if photos of plot are taken)
- **Plot Contact Info** – If available, record contact person's name and phone number. For residential land uses, do not ask for this information. However, if name is on mailbox, record it. Owner/renter status is useful if it comes up in conversation.
- **Reference objects****(at least two are required) – identify/describe the object (minimum of two fixed objects must be recorded with distance and direction) plot center must be identified so that it can be located in future remeasurements of the plot. Identify at least 2 landmarks visible when standing at plot center. Try to use objects that are likely to be present 5 to 15 years from now, e.g. stop signs, telephone poles, permanent structures, sidewalks/driveways. If plot falls in forested area and there are no man-made or permanent objects within sight, select two unique trees (species or DBH), witness trees, that you expect to be present on the plot for a reasonable period of time. Photo(s) of measured objects are helpful if plot center is difficult to determine.
- **Distance to object****
- **Direction to object** (in degrees)**
- **Tree measurement point**** If plot center falls on a building or other surface (such as highway) where plot center cannot be accessed, the plot is not to be moved. All distances and directions to trees are to be measured and recorded from a building corner or other fixed point. Make notation of "tree measurement point" on the notes section. On this line/space describe what/where tree measurement point is. (See Appendix A. for further instructions.)
- **Slope***** thru plot center – record to nearest 1%. If slope is < 5%, record as 0%. Slope is determined by sighting the clinometer along a line parallel to the average incline (or decline) through the center of each plot. To measure Slope, Observer 1 should stand at the uphill edge of the plot and sight Observer 2, who stands at the downhill edge of the plot. Sight Observer 2 at the same height as the eye-level of Observer 1. Read the slope directly from the percent scale of the clinometer.
  If slope changes gradually across the plot, record an average slope. If slope changes across the plot but the slope is predominately of one direction, code the predominate slope percentage rather than the average.
- **Aspect*** –** record to nearest 1 degree. Record the predominant direction water will run at plot center and take compass reading. If the slope of the plot is less then 5% then the aspect is recorded as 0 ; 1 = 1 degree; 2 =2 degrees; … 360 = 360 degrees, due north
- **Measurement Units* (M/E) -** Metric (m/cm), English (ft/in). This variable notes the type of measurement used for all variables that require ft/m or in/cm measurements.

The following plot information is recorded for each land use (for split plots). If the plot does not have more than one land use, these variables are only recorded once for the entire plot. If the plot is split between two land uses, then the following information is needed for both land uses:

- **Actual land use*** - actual land use as determined by the crew on the ground (i.e., not necessarily the land use noted from land use maps).

Land Use	Code	Land Use	Code
Residential	R	Institutional	I
Multi Family Residential	M	Transportation	T
Comm / Ind	C	Utility	U
Park	P	Water / wetland	W
Cemetery	E		
Golf Course	G		
Agriculture	A		
Vacant	V		

Land Use clarification: **Multi Family Residential** is defined as 3+ family structures. **Vacant** land has no apparent use. Boarded up buildings are classified as the original designated use of the structure. **Transportation** use is reserved for limited access roadways (usually fenced), train tracks, airports, shipyards, etc. If plot center falls in street, plot is classified as the adjacent land use.

- **Percent in*** - proportion of the plot that is in the land use as determined by the field crew. For most plots, this number will be 100%. However, some plots will fall on a border between two or more land uses. For example, 40% of the plot area might be residential and 60% vacant. In this case, the plot is split into two separate plots (one for the residential area and one for the vacant area) and all data are recorded on the data sheets for each land use (i.e., collect all data for the 40% residential area; then collect all data for the 60% vacant area). When working on the residential area, "Percent in" would equal 40%; when working on the vacant area, "Percent in" would equal 60%. However, each side of the plot is considered to be independent, such that there are now 2 separate plots that are each less than 1/10 acre. No data collection procedures change except the crew is working in a smaller area and data are collected on two plots. Plot ID should be noted with a decimal suffix for each plot with two or more land uses. For example, if plot number 14 is split, one plot would be noted as 14 and the other as 14.5. Land use differences must be clearly identifiable on the plot. There must be a clear change in human use of the land, not just it's cover or ownership
- **Plot Tree Cover (%)*** - the amount of tree canopies covering the plot. When looking upward from within the plot, one will either see tree canopies or open sky areas between the canopies. This datum is the proportion of the sky that is obscured by tree crowns within the plot and will range from 0 to 100%. Tree cover can come from trees located outside the plot; so plots not containing trees could have tree cover. Record to nearest 5% unless cover is minimal. If trace amount present; 1,2,3%, etc. is acceptable.
- **Plot Shrub Cover (%)***** – percent of the plot area covered by shrub canopies. The difference between trees and shrubs is explained in Section 4.2. Don't double-count multiple layers of shrubs. Look down from above. Record to nearest 5% unless cover is minimal. If trace amount present; 1,2,3%, etc. is acceptable.
- **Plantable space** - percent of the plot area that is plantable for trees (i.e., plantable soil that is not filled with tree canopies above (or other overhead restrictions) and tree planting /establishment would not be prohibited due to land use (e.g., footpath, baseball field, etc.)). Planting underneath utility wires is ok. Record to nearest 5% unless. If trace amount present; 1,2,3%, etc. is acceptable.

*2. Ground Cover Information****

Within the plot, various materials will cover the ground (trees and shrubs are considered separately; tree stems as a ground cover are ignored). The crew should note what proportion of the plot ground area is covered by the following materials:

- buildings (%BLDG)
- cement (%CMNT)
- tar - blacktop/asphalt (%TAR)
- other impervious (%OTHIMP)
- soil (%SOIL) (including naturally occurring sand)
- perm rock (%PERM ROCK) – permeable rock surfaces such as gravel. Brick or flagstone walkways or patios (without mortar). Sand in playgrounds or added as topping to existing soil. Large solid rock outcrops would be listed as other impervious.
- duff/mulch (%DUFF/MULCH)
- herbaceous - low herbaceous ground cover, exclusive of grass, including agricultural crops (%HERB/IVY)
- grass – mown/maintained grass (%MAIN.GRASS)
- wild, unmaintained grass (%UNMAIN.GRASS)

- water - including pools (%H2O)

Record to nearest 5% unless cover is minimal. If trace amount present; 1,2,3%, etc. is acceptable. The sum of these proportions above must add to 100% per plot

Use the following chart as a guide when estimating one and five percent increments of cover. (Some examples for comparison: queen size mattress covers 25 sq. ft., standard, full size (4 door) Sport Utility Vehicle (SUV) =covers 90 sq. ft.)

Plot Size	1/6th acre		1/10th acre		1/24th acre		1/75th acre	
Plot Radius (ft.)	48.1		37.2		24.0		13.6	
1% plot area (sq. ft.)	73	5' radius	43	3.5' radius	18	2.4' radius	6	1.4' radius
5% plot area (sq.ft>)	363	11' radius	217	8' radius	90	5' radius	29	3' radius

3. Shrub information*** (Shrub information can be used to estimate pollution removal by shrubs.)

A certain proportion of the plot may be occupied by shrubs (e.g., shrub cover may be 30%). If shrubs are present on the plot, this section of the data sheet focuses just on the shrub area. Thus, the shrub area (30% of the plot in this example) is the only area where data are collected. The following data are recorded for the each shrub species group of similar height (i.e., many shrubs of the same species and height can be combined for the shrub estimate:

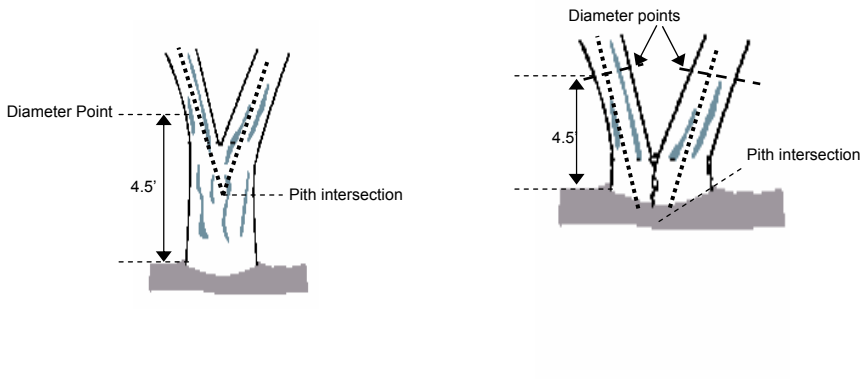
- **Species******* – (see Appendix B). If not known, note genus. The species must be identified to its genus as a minimum, if genus is not known then procure a sample to be identified at a later date. A tree with DBH < 1 inch is considered a shrub.
- **Height******* – height (ft or m) of the shrub mass for the species
- **Percent Area******* - Of the total ground area of all shrubs on the plot, what percent of the ground area is occupied by this species/height combination (0-100%). Total of all % area values recorded on the plot **may exceed 100%** if there are two or more layers of shrubs on the plot.
- **Percent Shrub Mass Missing******* - Of the volume (height x ground area)of this species/height combination, the percent of the volume that is **missing**, i.e., not occupied by leaves. The shrub mass leaves are assumed to start at the ground. This category allows field crew to account for voids in vegetation and inaccuracies of simple height x area estimates (e.g., height of mass might not be uniform). Allow for natural arrangement or spacing of leaves; however, the field crews should investigate the interior of the shrub mass to better estimate the missing portions. In the past crews have underestimated the mass missing by not accounting for the interior (this only applies to shrub masses). Intent of this variable is to adjust height and area measurements to reveal actual volume of leaves.

4. Tree information

Data collection for trees starts with the tree to the north and then proceeds in a clockwise direction.(Note: flagging or chalking each tree as it is measured will help keep track of trees once they are measured and prevent missing or double-entering a tree. No permanent marks, such as paint or scribe marks are allowed. If any sprouts of a tree are not attached to the main stem (e.g., root sprouts) and the sprout DBH reaches tree dimensions, then the sprout is recorded as a separate tree. For each tree, living or dead, within the plot with greater than ½ of its stem in the plot and DBH ≥ 1 inch, the following data are recorded:

- **DR**** - direction from plot center to the tree (living or dead) in compass degrees / azimuths (e.g., North = 0^o; East = 90^o; South = 180^o) (This variable is collected only for permanent plots). (If plot center is inaccessible, i.e. on top of building or in highway, measure direction from **tree measurement point.** (See instructions in Appendix A.)
- **DS**** - distance, measured parallel to ground, to tree (living or dead) from plot center measured in ft or m (This variable is collected only for permanent plots). (If plot center is inaccessible, i.e. on top of building or in highway, measure distance from **tree measurement point.** (See instructions in Appendix A.)
- **SPECIES*** - if species is not known, take sample and record in notebook as unknown #1 etc. Every time that same unknown is encountered, it will be recorded as unknown #1. Sequentially number unknowns in notebook and try to identify later. Each unknown tree with a number is unique to a specific species. If identification of individual species is difficult (e.g., due to hybridization) or individual species is not known, then record genus if possible. Codes are given in PDF Species List. For dead trees when species or genus cannot be determined, record UNKN.
- **NUMBER OF DBHs RECORDED*** – if tree is forked (see DBH below), record up to 6 DBH measurements. The field is the number of DBH measurements taken
- **DBH*** – diameter of each living and dead tree at breast height (4.5 ft) on the uphill side of tree, measured in either in or cm, to the nearest $1/10^{th}$. See Appendix C.

  Forked tree: If the point of pith separation (see below) is above ground, the plant is considered to be one tree. Measure each DBH separately up to six measurements. If the tree has more than six stems at DBH, with at least one of the stems one inch in diameter, move down to the highest point above ground where there is a single stem and measure the diameter there as long as there are no deformities (see Appendix C). Record the height where diameter was measured.(If none of the stems are greater than one inch, it is considered a shrub,)If the pith union is below ground, each stem is considered a separate tree. (Included bark down to ground line is a good indicator that pith union is below ground.)



- **DBH MEASUREMENT HEIGHT** – if diameter is not measured at 4.5 feet, height of measurement of diameter is recorded.
- **TOTAL HEIGHT*** - height to top (alive or dead) of tree measured in ft or m. *Tree height must be recorded for all trees, including dead trees.* For downed living trees or severely leaning trees, height is considered the distance along the main stem from ground to tree top.(Record to nearest ft. or meter) (See Appendix D.)
- **HEIGHT TO CROWN BASE***- height to base of live crown measured in ft or m. Record dead trees as 0. (Record to nearest ft. or meter.)
- **CROWN WIDTH*** - crown width measured in ft or m. Crown width is recorded by two measurements: N-S (North-South) and E-W (East-West) widths. Dead trees always have a crown width of 0. If tree is downed or leaning, take width measurements perpendicular to the tree bole. (Record to nearest ft. or meter.)

- **PERCENT CANOPY MISSING*** –the percent of the crown volume that is **not** occupied by leaves. Within the "typical crown outline," estimate the percent foliage that is absent. (Subtract missing areas due to pruning, dieback, defoliation, uneven crown, or dwarf or sparse leaves.) The typical crown outline is defined as a symmetrical silhouette created by the live crown width, total height, and height to base of live crown measurements. It is assumed to be symmetrical around the center point of the measured width of the tree and filled with leaves as if it were a healthy tree in excellent condition. This measure estimates the percent of leaf mass that is absent in the outline as compared to a healthy tree with a full symmetrical crown. Do not include normal interior crown voids due to leaf shading. Take into account the natural crown shape for the particular species. Two perpendicular measures of missing leaf mass are made and the average result is recorded. Record to nearest 5%. (See Appendix D)

- **DIEBACK*** - Percent crown dieback in crown area. This dieback does not include normal/natural branch dieback/pruning due to crown competition/shading in the lower portion of the crown. However, branch dieback on side(s) of crown area due to shading from a building or another tree would be included. Estimate dieback in the following categories: E = < 1% dieback, G = 1-10%, F = 11-25%, P = 26-50%, C = 51-75%, D = 76-99%, K = 100% (See Appendix E)
- **% IMP***** – Percent of land area beneath entire tree canopy's drip line that is impervious. If tree crown crosses out of plot boundary, entire area beneath tree is still estimated.
- **% SHRUB*** -** Percent of land area beneath canopy drip line that is occupied by shrubs. If tree crown crosses out of plot boundary, entire area beneath tree is still estimated.
- **CLE* –** Crown Light Exposure: Recorded on a scale of 0 – 5. Number of sides of the tree receiving sunlight from above. Top of tree is counted as one side. Divide the crown vertically into four equal sides. Count the number of sides that would receive direct light if the sun was directly above the tree. The top of the tree counts as an additional side (Figure 1).

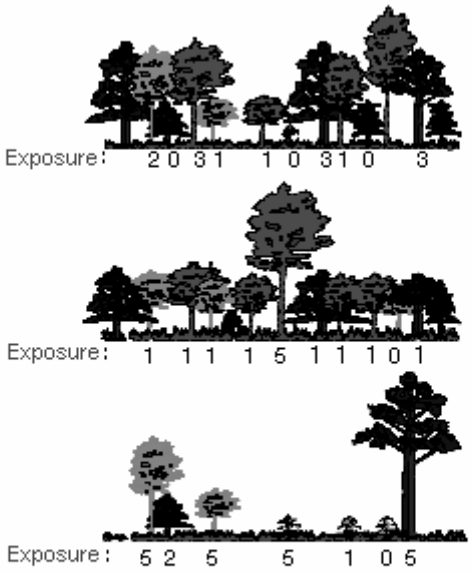


Figure 1. Crown Light Exposure

Note: 1/3 of the live crown must be receiving full light in order for a side to qualify. A sliver of a side receiving light does not qualify.

Crown Light Exposure Codes.

Code	Definition
0	The tree receives no full light because it is shaded by trees, vines, or other vegetation.
1	The tree receives full light from the top or 1 side.
2	The tree receives full light from the top and 1 side (or 2 sides without the top).
3	The tree receives full light from the top and 2 sides (or 3 sides without the top).
4	The tree receives full light from the top and 3 sides.
5	The tree receives full light from the top and 4 sides.

- **No. Build –** The number of buildings that are interacting with trees (within 60 ft. and are less then 2 stories in height)**.**
- **D#*** - direction **to** building. For trees (>= 20 ft. tall) that are located within 60 feet of residential buildings that are 3 stories (2 stories & attic) in height record the direction (azimuth) **to** the closest part of the building. This should be noted in degrees. **Note:** some trees may be within 60 feet of more than one building; in this case; record additional data to D2 and S2 for second building, D3 / S3 for third building, etc. If more space is needed to record data, create additional columns with the appropriate number. Buildings the tree affects do *not* have to be located on the plot. **Note:** the energy analyses are currently set to run for typical building types and climate zones of the United States.
- **S#***- shortest distance to the building measured in ft or m. Measure to closest wall or to corner of bldg (for tree planted on corner)
- **S** - street tree; Y if a street tree; N if not a street tree.
- **N/R** – New/removed tree. Indicate the reason the tree was added or removed from the plot since the previous survey (used for remeasurements of permanent plots):
  - P – planted: new tree since last measurement that has been planted
  - I – ingrowth: new tree since last measurement that existed in last measurement and has now reached tree size or has seeded in and has reached tree size
  - U – unknown new: new tree but for unknown reason
  - R – unknown removed: tree removed but for unknown reason
  - H – hazard/health problem: tree removed for health or safety reasons
  - C – healthy – homeowner removed: healthy tree removed due to homeowner choice
  - L – land use change: tree removed due to land use change (e.g., development of site)

SUMMARY NOTE FOR DEAD TREES: Record DR, DS, Species (if known, UNKN if unknown), DBH, Total Height, Height to Crown Base (record as 0), Crown Width (record as 0) and Dieback (record as K).,

D. Minimum Data Requirements

This section summarizes the minimum data that need to be collected to run a UFORE analysis.

For sampling an area, the following variables are required:

- Plot ID
- Land Use from map
- Measurement Units (Metric/English)
- Actual land use
- Plot Tree Cover (%)

For both sampling and inventories, the following variables are required[3]:

- Tree Species
- Number of DBHs recorded
- DBH
- DBH measurement height
- Total height
- Height to crown base
- Crown width
- Percent Canopy Missing
- Dieback
- CLE – crown light exposure
- D# - direction to building (needed for energy conservation only)
- S#- shortest distance to the building (needed for energy conservation only)

[3] Formulas are currently being developed to allow existing street tree inventories with only species, DBH and condition information to be used. However, this requires estimating all the other variables for a street tree population based on average data or regression equations from existing data. This type of conversion will allow for reasonable estimates for the inventory population, but estimates for individual trees will be inaccurate as the information on the tree was not collected and average data were used as a proxy. Collecting all variables will provide for the most accurate estimates.

E*. Computer Data Files*

Four files are required as input into the UFORE model:

1. Land use area
2. Original land use
3. Plot information
4. Tree information

The files should be sent in Excel (.xls), DBASE (.dbf) or comma-delimited (.cvs) format. Please include what version of the program the file was saved. For all files, the first row should be a header file with column name at top. For the examples given below, it will be assumed that files are in Excel format.

1. Land Use Area

This file provides the basic information on the stratum used in the sampling (not required for inventories). Total of all the land uses should add up to the total of the study area. For example, column A might be "RES"; column B: Residential; and column C: 12,400 (column C would be determined by land use map used to make the stratification).

Spreadsheet Column	Name of Column	Description
A	Code	Short alphanumerical (1-5 characters) code for landuse types used to stratify the plots (A,B,C). .
B	Landuse Descrip.	Text description of the land use type (up to 15 characters), e.g. Residential
C	Area (acres)	Total area of the land use type within the sampled city, in ACRES.

This file should be named: total.xls

2. Original Land Use

This file assigns each plot to its corresponding land use as given in the original stratification (see 1. Land Use Area above). This file is not required for inventories. It also assigns a unique plot number to each plot. For example, plot one may be residential according to the land use map, so column A would be "1"; column B would "RES".

Spreadsheet Column	Name of Column	Description
A	Plot No.	The id of the plot. Must be a numerical value. Do not include split plots
B	Original Landuse	Short alphanumerical (1-5 characters) code for landuse types used to stratify the plots. These codes must be the same codes as in Land Use Area file, column A.

This file should be saved as landuse.xls

3. Plot Information

This file contains the cover information for the plot (see section 4.C.1-2) (not required for inventories). Many of the plot variables that were collected (e.g., plot address, date, crew, GPS coordinates, photo #, contact information, landmarks, measured reference object information) are not needed for the UFORE analysis, but are required to help find the plot in the future (permanent plot information) to help assess change. These variables (if collected), should be recorded and saved for future use. An additional Excel file of these variables could be made and sent in with the original files if desired.

Spreadsheet Column	Name of Column	Description
A	PLOT I.D.	The id of the plot. Must be a numerical value. For split plots, decimals should also be used. Maximum of 2 landuses per split plot. For example, if plot 120 was split into 2 land uses, the plot ID would be 120 and 120.5 for the two parts of the plot.
B	LANDUSE	Short alphanumerical (1-5 characters) code for landuse type as found in the field.
C	% IN	The percent of the plot (Column A) within land use (Column B)
D	% BLDG	Percent of the plot covered with building.
E	blank	Insert a period (.) in this column
F	blank	Insert a period (.) in this column
G	blank	Insert a period (.) in this column
H	blank	Insert a period (.) in this column
I	% CEMEN	Percent of plot covered in cement.
J	% TAR	Percent of plot covered in tar/asphalt.
K	%OTH IMP	Percent of plot covered in other impervious.
L	% SOIL	Percent of plot covered in soil.
M	% PERMROCK	Percent of plot covered in permeablerock.
N	% DUFF/MUL	Percent of plot covered in duff/mulch.
O	% HERB/IVY	Percent of plot covered in herb/ivy.
P	% GRASS	Percent of plot covered in maintained grass.
Q	%W. GRAS	Percent of plot covered in wild/unmaintained grass or weeds.
R	% WATER	Percent of plot covered in water.
S	% SHRUB	Percent of plot covered in shrub.
T	%TREE	Percent of plot covered in tree.
U	% PLANTABL	Percent of plot covered in plantable space.
V	MEASURE	Measurement Units (E – English; M – Metric)
W	SLOPE	Plot slope (percent)
X	ASPECT	Plot aspect (degrees)

This file should be saved as: plot.xls

4. Tree Information

This file contains information on the individual trees and shrub masses. This file is required for all UFORE analyses, including inventories.

Spreadsheet Column	Name of Column	Description
A	PLOT ID	The id of the plot that the tree is on. Must be a numerical value. For split plots, decimal should be used (see plot file information above
B	SPECIES	UFORE alphanumeric species code.
C	# of STEMS	Number of DBHs present in columns D thru I.
D-I	DBH1-6	Place numbers in the appropriate columns.
J	TREE HT	Tree height. For shrub – the column is height of shrub mass
K	BOLE HT	Bole height (height to crown base).
L	CRWN WIDTH	Mean of the two crown width measurements.
M	DIEBACK	Alphabetical code for dieback where E = < 1% dieback, G = 1-10%, F = 11-25%, P = 26-50%, C = 51-75%, D = 76-99%, K = 100%.
N	% AREA	For shrubs only, percent of the total plot shrub area in this species.
O	% Missing	Percent of the **tree canopy** missing, not including dieback. This column is also filled for **shrubs** as "% shrub mass missing".
P	NUMBER	Unique tree/shrub identification number. Each id must be unique within the entire sample of the city.
Q	SHRB IND	Code indicating that the entry is a tree (T) or a shrub (S).
R	NO. BLDGS	The number of building/tree interactions (up to 3) in S-X. , count number of bldg/tree interactions. If more building interactions are found for a tree, note these additional interactions in a separate file along with unique plant ID number (above).
S	BLD DIR 1	The direction from the tree to the building #1
T	BLD DIS 1	The distance of the tree from the building #1.
U	BLD DIR 2	The direction from the tree to the building #2
V	BLD DIS 2	The distance of the tree from the building #2
W	BLD DIR 3	The direction from the tree to the building #3
X	BLD DIS 3	The distance of the tree from the building #3.
Y	STREET (MUNICIPAL)	Indicates street (municipal) tree (Y) or non-street (municipal) tree (N).
Z	CLE	Crown light exposure value
AA	DBH HT	Height that DBH was measured (ft or m)
AB	% IMP	% area below tree canopy that is impervious
AC	% SHRUB	% area below tree canopy that is occupied by shrub cover
AD	N/R	New/removed tree. Code indicating reason tree was added or removed from the plot since the previous survey (used for remeasurements of permanent plots)

This file should be saved as: tree.xls

5. Air Pollution Data

Air pollution data are not required if the data are collected in the United States. However, if the data were collected elsewhere, hourly air pollution data should be in a Microsoft Excel format. The column names and data reported should be as follows:

Spreadsheet Column	Name of Column	Description
A	Year	The year the data were recorded
B	Month	The month the data were recorded
C	Spname	Name of pollutant
D	Cityname	The name of the city where the pollution monitor is located
E	Addr	The address of the pollution monitor
F	Quantity	The concentration of the pollutant in ppm for CO, NO2, O3, SO2; and in $\mu g/m^3$ for PM10
G	Day	The day the data were recorded
H	Hour	The hour the data were recorded

F*. Equipment*

The following are field equipment that are needed for UFORE plot measurements:

- Aerial photographs and street map to locate plot
- Clinometer or some other device to measure tree height
- Diameter tape or some other device to measure tree diameter
- Clipboard; data sheets, pens/pencils (or digital recorders-PDA)
- 50/100 ft tape measure (or electronic measuring device)
- Species ID guide
- Notebook, clippers, and tape to record and store unknown samples
- First Aid Kit
- Calculator
- Compass
- Dazzer (to ward off dogs)
- Camera (if taking pictures of plot)
- Chalk/Flagging (to mark trees that have been measured in plots with many trees)
- Binoculars

G. Safety

Safety is a critical component of any field operation. In cities, differing neighborhood condition can cause potential safety hazards. Be aware of the surrounding environments and use caution at all times. Discuss with local project managers specific conditions that may be encountered within the city. Also contact local police for more information, if necessary, and to let the police know that the field operation is occurring. Leave daily itineraries with the project manager regarding the area of the city to be sampled. See Tallent-Halsell, N.G. (ed.) 1994. Forest Health Monitoring 1994 Field Methods Guide. EPA/620/R-94/027. U.S. Environmental Protection Agency, Washington, DC. for more information on safety procedures.

5. Appendices

Appendix A – Plot Center on Building

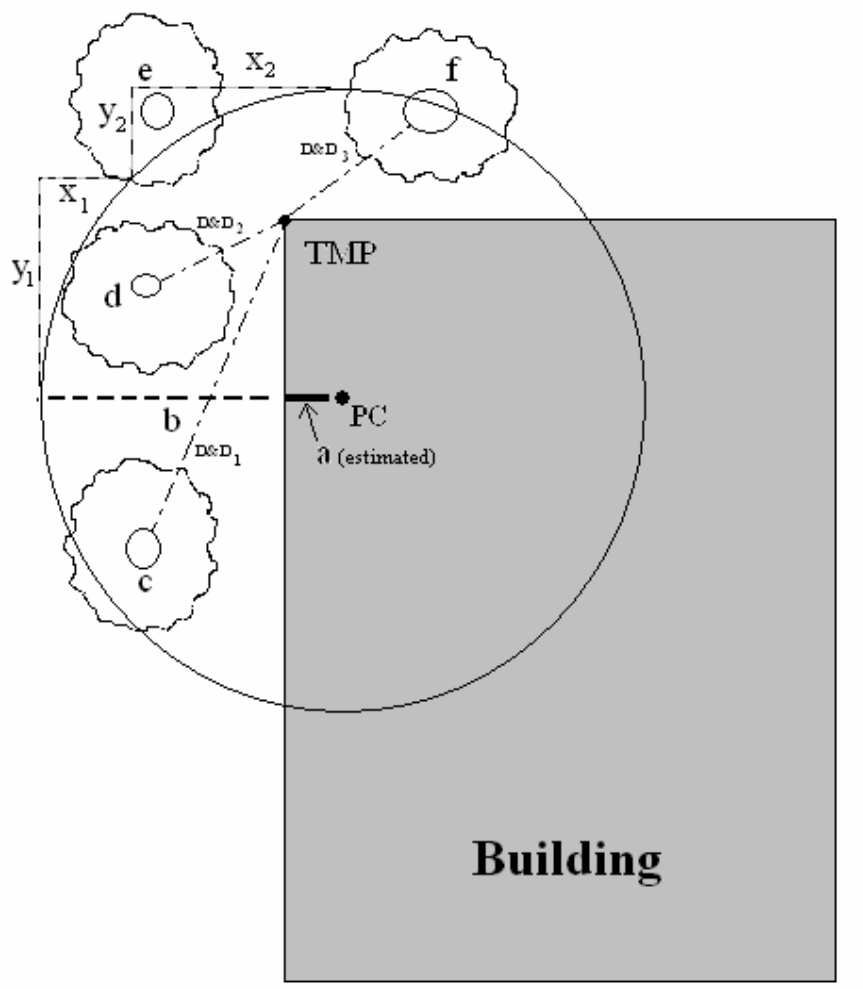


Figure A-1.
PC – Actual Plot Center TMP – Tree Measuring Point D&D – Distance & Direction

The following describes how to determine plot boundaries and location of trees with plot centers that are located on buildings. Determine 'a' by estimating the approximate location of the actual plot center from aerial photo or cover map. Then calculate 'b' by subtracting 'a' from the limiting distance of the plot (ex. 1/10 acre plot limiting distance is 37.2 ft.). Then 'b' is the distance from the plot boundary to the building's wall.

To outline the general plot boundary walk parallel to the building for 26.2 ft (y_1), then perpendicular to the building for 11ft (x_1). This would represent a point along the boundary approximately 45° along its edge. If one then walked 11 ft (y_2) parallel to the buildings edge, and 26.2 ft (x_2) perpendicular the next plot boundary would be reached; representing a place 90° from the PC. **This example is for a 1/10 acre plot only.**

In order to create a more efficient tool to locate the trees that are in-plot the crew must first determine the plot boundaries as described above, and then locate a point from which a distance and direction can clearly be delineated. In figure 1. (above) TMP, or Tree Measurement Point,8 is chosen (notes should be recorded as to which corner of the building was chosen ex. North-West corner). Record the trees starting at 0° and rotating in a clockwise direction. Trees 'c', 'd', 'f' are all within the plot boundary first delineated, as such they must be tallied; tree 'e' on the other hand is outside the plot boundary and is not tallied. Even though the plot center is moved to create an easier method to locate

the trees in plot no tree can be either added, or removed, due to the change in plot center location (moving from PC to TMP).

e.g. Tree ‘e’ is not within 37.2 ft of the actual PC, but it is within 37.2 ft of the TMP it is still not tallied because of the aforementioned conditions. This example is for a 1/10 acre plot.

Appendix B. Field Data Sheets

Location Year Plot ID:

Date Crew Field Land Use Percent In Completed:

Two Land Uses Must be Entered for Split

Split Plot ***** If it is a split plot then two separate data sheets must be used for following categories. *****

Plot / Contact Information

Address Phone Number

Resident Notes:

GPS / Photograph

GPS X GPS Y GPS Z Photo #

Reference Objects

ID	Description	Direction	Distance	Notes/Comments (DBH)
1				
2				
3				

Percent of Plot

Tree Cover Shrub Cover Plantable Space

Ground Covers (Percents)

Building Cement Tar Other Impervious Main. Grass Unmain. Grass Duff/Mulch

Bare Soil Seedlings Herb/ Ivy Agri. Crops Pervious Rock Water

Ground Covers Must Add to 100%

Shrub Data

Shrub ID	Species Code	% Shrub Area	Height	% Mass Missing	ID	Species Code	% Shrub Area	Height	% Mass Missing
1					6				
2					7				
3					8				
4					9				
5					10				

Shrub Area Must Add to 100%

Notes:

Tree ID	Dist	Dir	Spp.	#DBH / Ht DBH	DBH1	DBH2	DBH3	DBH4	DBH5	DBH6	Crown Base	Tot Ht.	Crwn Width 1	Crwn Width 2	CLE	% Canopy Missing	Die Back	Interact#	Distance	Direction
																		1		
																		2		
																		3		
																		1		
																		2		
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Appendix C. DBH Measurement

From: Forest Inventory and Analysis National Core Field Guide. Volume 1: Field Data Collection Procedures for Phase 2 Plots. Version 1.4

Special DBH situations:

1. Tree with butt-swell or bottleneck: Measure these trees 1.5 ft above the end of the swell or bottleneck if the swell or bottleneck extends 3.0 ft or more above the ground (Figure C-1).
2. Tree with irregularities at DBH: On trees with swellings (Figure C-2), bumps, depressions, branches (Figure C-3), etc. at DBH, diameter will be measured immediately above the irregularity at the place it ceases to affect normal stem form.
3. Tree on slope: Measure diameter at 4.5 ft from the ground along the bole on the uphill side of the tree (Figure C-4).
4. Leaning tree: Measure diameter at 4.5 ft from the ground along the bole. The 4.5 ft distance is measured along the underside face of the bole (Figure C-5).
5. Live windthrown tree: Measure from the top of the root collar along the length to 4.5 ft (Figure C-6).

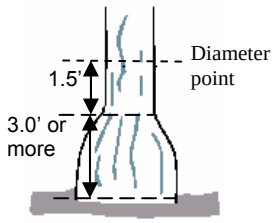

Figure C-1. Tree with swelled butt

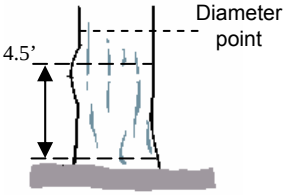

Figure C-2 Tree with swelling

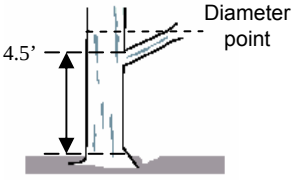

Figure C-3 Tree with branch

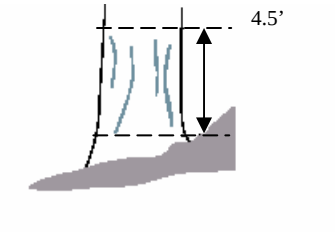

Figure C-4 Tree on a slope

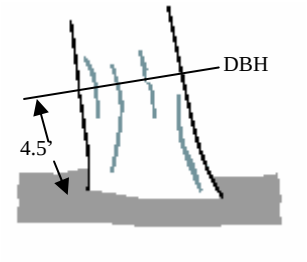

Figure C-5 Leaning tree

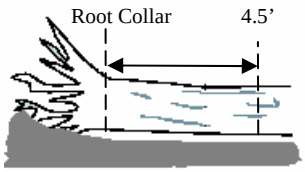

Figure C-6 Tree on the ground

Appendix D. Percent Canopy Missing & Base of Live Crown

Total height of tree is measured from ground up to top (living or dead) of tree. Many times there are additional live branches below the "base of live crown". The live crown base becomes that point on the main bole perpendicular to the lowest live foliage on the last branch that is included in the live crown. **The live crown base is determined by the live foliage and not by the point where a branch intersects with the main bole.**

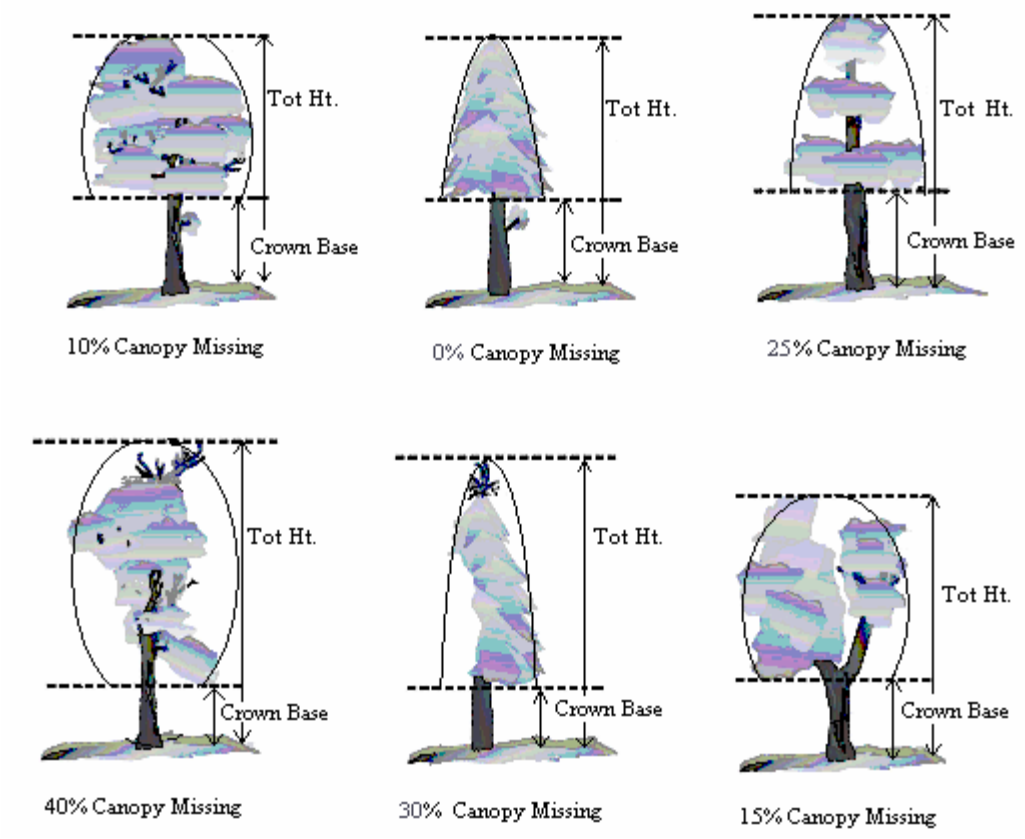

Figure D-1 Examples of Percent Canopy Missing and Crown Heights

Percent Canopy Missing is measured by two people standing perpendicular angles to the tree (Figure D-2). Typical and actual crown shape is determined by the measurements made for crown width, tree height, and height to base of live crown.

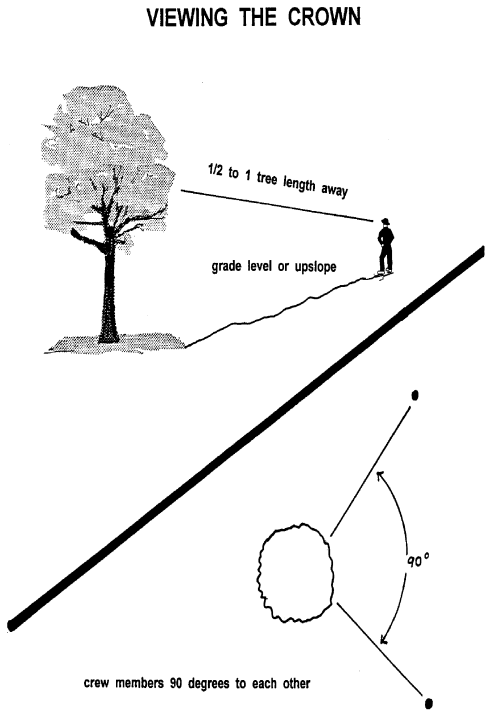

Figure D-2. Crew positions for viewing crowns.

When two individuals disagree with their estimates, follow the guidelines listed in Appendix F.

Appendix E. Crown Dieback

From: Forest Inventory and Analysis National Core Field Guide. Volume 1: Field Data Collection Procedures for Phase 2 Plots. Version 1.4

Crown dieback is defined as recent mortality of branches with fine twigs, which begins at the terminal portion of a branch and proceeds toward the trunk. Dieback should occur from the top of the crown down and from the outside in toward the main stem. Dieback is only considered when it occurs in the upper and outer portions of the tree. When whole branches are dead in the upper crown, without obvious signs of damage such as breaks or animal injury, assume that the branches died from the terminal portion of the branch. Dead branches in the lower portion of the live crown are assumed to have died from competition and shading. Dead branches in the lower live crown are not considered as part of crown dieback, unless there is continuous dieback from the upper and outer crown down to those branches.

Crown dieback estimates reflect the severity of recent stresses on a tree. Estimate crown dieback as a percentage of the live crown area, including the dieback area. Assume the perimeter of the crown is a two-dimensional outline from branch-tip to branch-tip, excluding snag branches and large holes or gaps in the crown (Figure E-1).

Crown dieback is obtained by two people (Figure D-2). Binoculars should be used to assist in the data collection. Observers should be conscious of lighting conditions and how light affects the day's observations. Under limited-light conditions, observers should take extra time. Poor lighting can make the measurement more difficult.

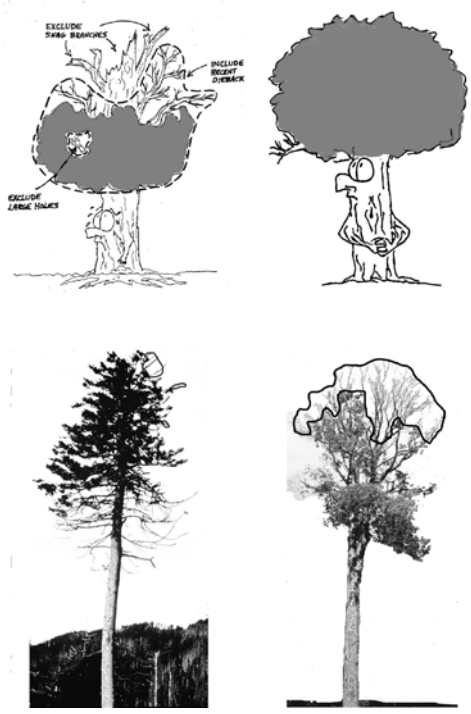

Figure E-1 Dieback rating examples.

Each individual should mentally draw a two-dimensional crown outline, block in the dieback and estimate the dieback area.

When two individuals disagree with their estimates, follow the guidelines listed in Appendix F. The estimate is placed into one of 21 percentage classes.

Appendix F. Crown Rating Precautions

Crews must be especially careful when making evaluations under certain conditions and follow these procedures:

Distance from the tree -

Crews must attempt to stay at least 1/2 to 1 tree length from the tree being evaluated. Some ratings change with proximity to the tree. In some situations, it is impossible to satisfy this step, but the crew should do the best it can in each case. All evaluations are made at grade (same elevation as base of the tree) or up slope from the tree. This may not be possible in all cases but never get in the habit of evaluating trees from the down slope side.

View of the crown -

Crewmembers should evaluate trees when standing at an angle to each other, striving to obtain the best view of the crown. The ideal positions are at 90 degrees to each other on flat terrain (Figure D-2). If possible, never evaluate the tree from the same position or at 180 degrees. In a forest, getting a good perspective of the crown becomes difficult. Overlapping branches, background trees and lack of a good viewing area can cause problems when rating some trees. Crews need to move laterally to search for a good view. Take special care when rating such trees.

Climatic conditions -

Cloudy or overcast skies, fog, rain and poor sun angles may affect estimates Crown diameters may be affected but to a lesser degree than other crown indicators. Crown dieback may be underestimated, because it is difficult to see dead twigs and/or to differentiate defoliated twigs from dead twigs. Crews need to be especially careful during poor lighting conditions. Crews should move around a tree to get another view, even if the view appears adequate at a specific location.

Heavy defoliation -

During heavy defoliation, crown dieback may be overestimated. The use of binoculars may help in separating dead twigs from defoliated twigs.

Trees with epicormics or sprigs -

Trees that are densely covered in epicormic sprouts are not considered special cases in field data collection. There are two methods for handling this situation. The first choice is to not consider epicormic sprouts as part of the live crown base (if located under the actual branches crown base). The foliage the epicormics do produce for the tree would be considered for the percent canopy missing, overall decreasing the amount of percent canopy missing.
E.g. A tree has epicormic sprouts extending to four feet from the ground, but its live crown base is measured at eight feet high. The crew estimates the percent canopy missing at 15%, but also estimate the additional four feet of epicormic sprouts to contain approximately 5% of canopy cover. The percent canopy missing would then be recorded as 10%. All of the percentages would be based on the crown measurements (crown widths, total height, and crown base height).

The second way would be to lower the crown base measurement to the lowest epicormic sprout, and then that point would be utilized to estimate the percent canopy missing of the tree. More times then not this method will increase the percent canopy missing.

Either way in handling epicormic sprouts will work in the UFORE model, but in the field, it is more useful to be consistent. Use one method or the other for most, if not all, of the cases when encountering epicormic sprouts.

If a tree's canopy is consisting of only epicormic sprouts, or if they are located above the crown base, then they will be considered for the trees canopy. Measure them as if they were the crown.

Measurement differences resolution -

If the numbers for a crown measurement estimate by two crewmembers do not match, arrive at the final value by:

- Taking an average, if the numbers differ by 10% (2 classes) or less.
- Changing positions, if the numbers differ by 15 % or more and attempt to narrow the range to 10% or less.
- Averaging the two estimates for those trees that actually have different ratings from the two viewing areas (ratings of 30 and 70 would be recorded as 50)