treecm: an introduction

Marco Bascietto

April 7, 2012

1 Examples

1.1 Plot centre of mass

We will make use of the data set bundled in the package to plot a basic view of masses of branches and logs of a stone pine (*Pinus pinea* L.) sampled by the author:

```
> library(treecm)
> data(treeData)
> print(treeData)

$fieldData
    azimuth dBase dTip length tipD height tilt toBePruned pathToTip    biomass
L1      275    73   41   10.2 2.50   0.00   80      FALSE      TRUE 1488.17480
L2      275    41   16    3.9 2.75  10.20   80      FALSE      TRUE  157.22803
B1      190    15    0     NA 7.95  10.10    0      FALSE     FALSE  119.69839
B2      200    22    0     NA 7.95  10.40    0      FALSE     FALSE  246.69214
B3      230    15    0     NA 7.95  10.40    0      FALSE     FALSE  119.69839
B4      200    18    0     NA 7.95  11.15    0      FALSE     FALSE  168.88783
B5      180     7    0     NA 7.95  11.30    0      FALSE     FALSE   28.38618
B6      150     6    0     NA 7.95  11.30    0      FALSE     FALSE   21.21769
B7      340    16    0     NA 7.95  11.30    0      FALSE     FALSE  135.21104
B8      220    13    0     NA 3.95  11.80    0      FALSE     FALSE   91.35675
B9      165    19    0     NA 7.95  11.80    0      FALSE     FALSE  187.04037
B10     280     8    0     NA 7.95  11.90    0      FALSE     FALSE   36.52644
B11     170     9    0     NA 3.95  11.90    0      FALSE     FALSE   45.62402
B12     265     8    0     NA 7.95  12.20    0      FALSE     FALSE   36.52644
B13      75     6    0     NA 3.95  12.20    0      FALSE     FALSE   21.21769
B14     180     6    0     NA 7.95  12.20    0      FALSE     FALSE   21.21769
B15     170     6    0     NA 7.95  12.60    0      FALSE     FALSE   21.21769
B16     120     5    0     NA 7.95  12.60    0      FALSE     FALSE   15.03793
B17      10    14    0     NA 3.95  13.00    0      FALSE     FALSE  105.07799
B18     180    13    0     NA 7.95  13.00    0      FALSE     FALSE   91.35675
B19     260    13    0     NA 7.95  13.20    0      FALSE     FALSE   91.35675
```

```
B20       75      6     0      NA 3.95   13.20    0       FALSE     FALSE   21.21769
B21       75     10     0      NA 3.95   13.75    0       FALSE     FALSE   55.66636
B22      215      7     0      NA 7.95   13.75    0       FALSE     FALSE   28.38618
B23      140      7     0      NA 7.95   13.75    0       FALSE     FALSE   28.38618
C        275     16     0     3.0 3.00   14.10   80       FALSE      TRUE  135.21104

$density
[1] 530

$allometryFUN
function (x, diameter)
{
    a <- 0.7201
    b <- 1.8882
    powerEquation(a, b, as.real(x[diameter]))
}
<environment: namespace:treecm>

$branchesCM
[1] 1
```

This data set has been collected for a 17.1 metres tall stone pine whose stem was tilted approx. 20° from the vertical plane (or 80° from the horizonatal plane). The stem has been sectioned in two logs (`L1` and `L2`), and a final branch (`C`). These two logs and the final branch components have been defined in the field as the "main stem" of the tree, all the other components of the tree fall into the crown. The definition af the main stem is important only for the correct assessment of the position of the anchor on the tree, should the tree need stabilization with a steel cable. Main stem components get a `TRUE` value in the `pathToTip` column.

A component with `FALSE` or missing value in the `pathToTip` column is treated as it belonging to the crown. The crown was made up of 23 branches (`B1-B23`), all of them horizontal (*ie* tilted 0°).

Log and branch fresh biomass has alredy been calculated and added as `biomass` to `treeData$fieldData` data frame. Log biomass is computed by Smalian's formula (la Marca (2004)). Branch total (wood, leaves, fruits) fresh biomass is computed by `allometryAsca2011` function, wood fresh density is 530 $\frac{kg}{m^3}$. It is important to choose the most appropriate allometric equation in order to yield trustworthy biomass figures and, as a result, appropriate centre of mass coordinates. Allometry equations functions are discussed in section 2.3, page 16.

The package recognizes rows that represent branches because their diameter at tip (`tipD`) is 0.

Please notice that some rules have to be followed in order to record sound data in the field:

- the diameter of the tip of `L1` is equal to the diameter of the base of `L2`.

L2 tip diameter is, in turn, equal to C base diameter. Height figures must match between consecutive logs, as well as diameter measures do

- the distance of the tip of the branch (tipD) is not the length of the branch but the distance between tree base (the origin of the cartesian plot) and the branch tip
- note that length has been only recorded for the C branch (not considering logs) as it is the only branch not being horizontal. Non horizontal branches affect tree CM z-coordinate. When non-horizontal branches are present, and if one is interested in the z-coordinate of CM, than branch length and its angle from the horizonatl plane (tilt) should also be recorded. Otherwise branch length is not needed.

Branch and log biomass has been added to field measures and included in the treeData dataset by a simple call to treeData <- treeBiomass(treeData).

Let's get going and compute the centre of mass of this pine:

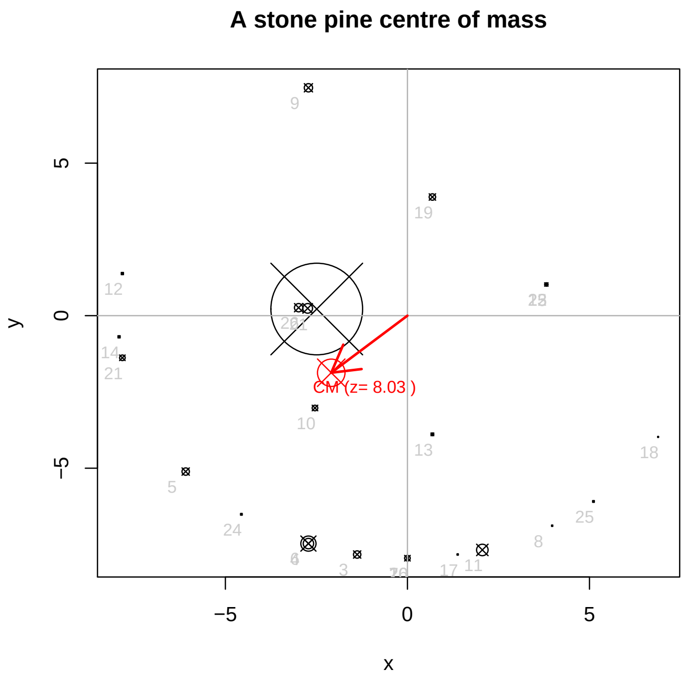
```
> vectors  <- treeVectors(treeData)
> CM       <- centreOfMass(vectors)
> summary(CM)

Coordinates of the centre of mass:
Cartesian (x/m, y/m, z/m): -2.09 , -1.87 , 8.03
Polar (angle/degrees, distance/m, height/m): 228 , 2.81 , 8.03
```

The core of the package is the summary method for CM class. The centre of mass for this stone pine lies 2.81 metres South-West of tree base (228° from magnetic North), 8.03 metres above ground. Cartesian coordinates are provided as well, though not so usefull as polar ones.

A simple visualization of tree centre of mass and its logs and branches is achieved simply by:

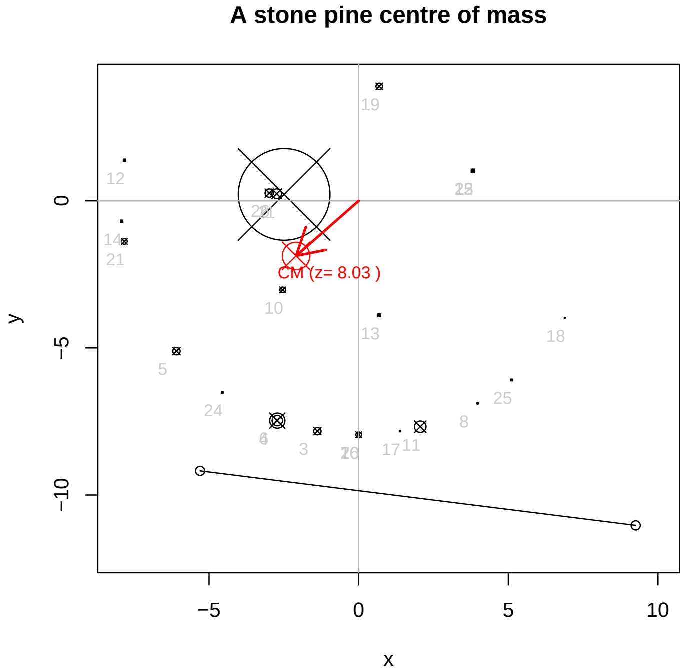
```
> plot(vectors, main = "A stone pine centre of mass")
> plot(CM)
```



In a cartesian coordinate system whose origin lies at tree base, the masses of logs and branches are plotted as vectors pointing inwards, towards the ground. Each circle represent a branch or log mass whose radius is proportional to branch or log mass. Likewise, the centre of mass is plotted as a vector pointing inwards, in red colour. Its height component is written alongside its label as z coordinate. A red arrow approximates the direction the tree will follow should it break at its base.

It is important that, should the tree break, it does not fall onto buildings or cause damage to people. We can add buildings and other important points to the CM plot provided that we measured the polar coordinates of their relevant points, from the the tree base, using the `plotPolarSegment` function. Let's add a building face facing the tree:

```
> plot(vectors,
+   main = "A stone pine centre of mass",
+   xlim = c(-8, 10),
+   ylim = c(-12, 4)
+ )
> plot(CM)
> plotPolarSegment(210, 10.6, 140, 14.4)
```



1.2 Snow load

Snow may increase crown load substantially, sometimes breaking entire branches. As a side effect, snow-loaded crowns may alter tree centre of mass by moving it upwards and, in asymmetric crowns, towards the part of crown under heavier load.

Let's model a snow load that doubles the biomass of branches higher than 12 m:

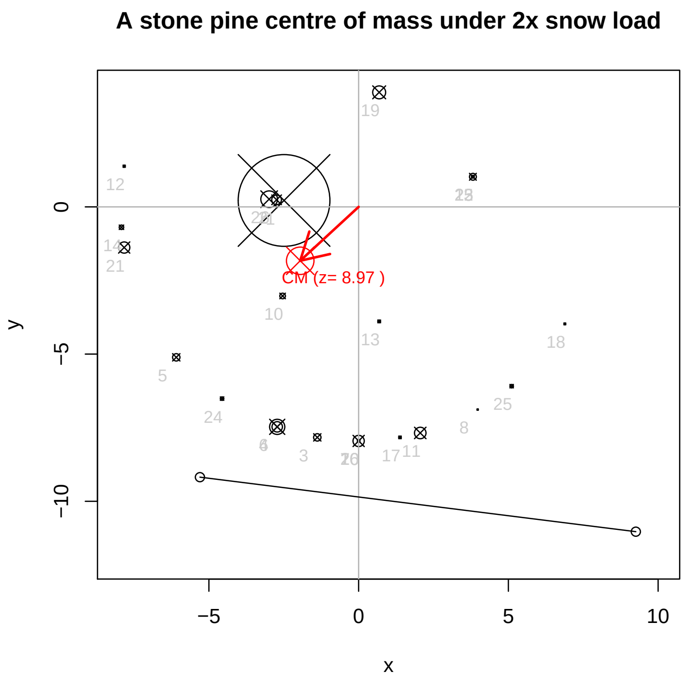
```
> rows <- substr(row.names(treeData$fieldData), 1, 1)
> q1 <- subset(treeData$fieldData, subset=(height < 12 | rows == "L"))
> q2 <- subset(treeData$fieldData, subset=(height > 12 & rows != "L"))
> q2$biomass <- q2$biomass * 2
> treeData$fieldData <- rbind(q1, q2)
> rm(list = c("q1", "q2", "rows"))
```

Let's recaltulate the vectors under snow load and plot the results:

```
> vectors  <- treeVectors(treeData)
> CM       <- centreOfMass(vectors)
> summary(CM)
```

```
Coordinates of the centre of mass:
Cartesian (x/m, y/m, z/m): -1.95 , -1.83 , 8.97
Polar (angle/degrees, distance/m, height/m): 226 , 2.67 , 8.97
```

```
> plot(vectors,
+   main = "A stone pine centre of mass under 2x snow load",
+   xlim = c(-8,10),
+   ylim = c(-12,4)
+ )
> plot(CM)
> plotPolarSegment(210, 10.6, 140, 14.4)
```



Tree centre of mass has clearly shifted upwards and towards the house...

1.3 Wind load

Winds may increase load on some sectors of the crown and decrease it in other sectors. We would like to model the effect of a prevailing Southbound wind that halves branches mass in the northern sector and doubles it in the southern sector.

```
> data(treeData)
> rows <- substr(row.names(treeData$fieldData), 1, 1)
```

```
> treeData$fieldData <- within(
+   treeData$fieldData, {
+   biomass[((azimuth >= 270 | azimuth < 90) & rows != "L")] <- biomass[((azimuth >= 270 | a
+   biomass[((azimuth >= 90 | azimuth < 270) & rows != "L")] <- biomass[((azimuth >= 90 | az
+ })
> rm(rows)
> vectors  <- treeVectors(treeData)
> CM       <- centreOfMass(vectors)
> summary(CM)
```

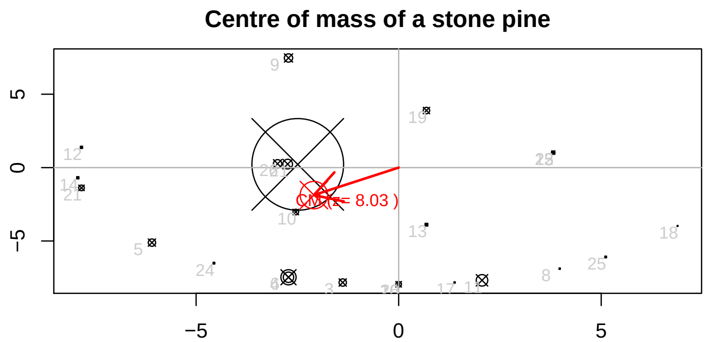
```
Coordinates of the centre of mass:
Cartesian (x/m, y/m, z/m): -2.04 , -3.10 , 8.99
Polar (angle/degrees, distance/m, height/m): 213 , 3.71 , 8.99
```

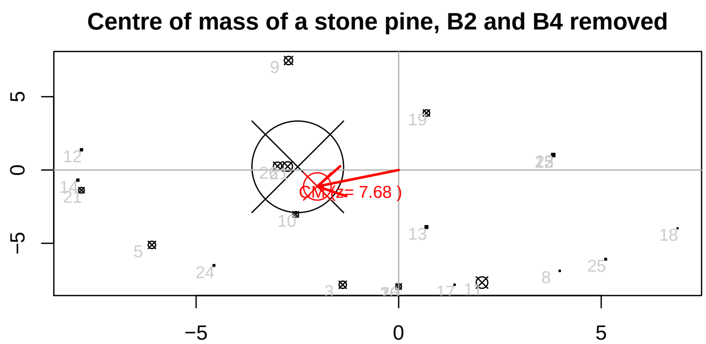
Under a heavy southbound wind the CM of the tree will move considerably towards South and 1 metre farther away from tree base. Although too simplicistic a model the results lead to the conclusion that dynamic forces in prevailing wind conditions should be taken into account when assessing tree stability.

1.4 Effect of pruning on CM

As far as static forces are concerned, in an effort to move centre of mass toward tree base, we could prune a few heavy branches. Let's have a look how CM would move if we cut `B2` and `B4`:

```
> library(treecm)
> data(treeData)
> vectors  <- treeVectors(treeData)
> CM       <- centreOfMass(vectors)
> op <- par(mfrow = c(2, 1), mai = c(0.5,0.5,0.5,0.2))
> plot(vectors, main = "Centre of mass of a stone pine")
> plot(CM)
> treeData$fieldData$toBePruned[c(4, 6)] <- TRUE
> vectors  <- treeVectors(treeData)
> CM       <- centreOfMass(vectors)
> plot(vectors, main = "Centre of mass of a stone pine, B2 and B4 removed")
> plot(CM)
> par(op)
> rm(op)
```





CM has actually moved towards tree base, and farther away from the house. As a matter of facts, branch pruning has been a slight reasonable action towards a safer tree.

1.5 Slenderness ratio

The slenderness ratio of a tree is a pure number defined as $SR = \frac{h}{d}$ where h is the height of the tree trunk, and d is the diameter of the tree Mattheck et al. (1995). The SR is a measure of tree stability and is extensively used in tree stability measures carried out by Visual Tree Assessment (VTA). SR in the range $30 \leq SR \leq 70$ are considered optimal, whereas $SR > 70$ lead to consider the tree at risk of breaking due to its excessive slenderness. The authors have applied the same concept to tree branches as well. While SR in vertical trees has a physical meaning Mattheck et al. (1995), branches are not usually vertical. As the branch starts to deviate from the verticality (as most of the branches do) the arm of the moment gets longer, reaching a maximum limit in horizontal branches. The longer the arm, the higher the stress on the branch. In order to estimate the added stress imposed by branch angle we improved Mattheck's formula by adding a component proportional to branch tilt angle:

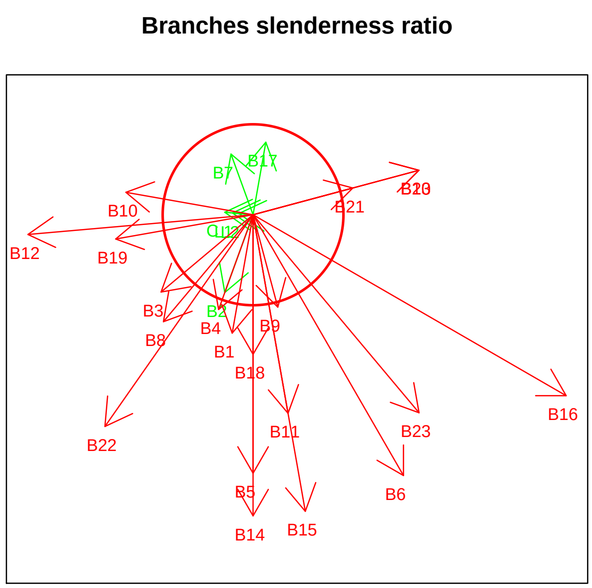
$SR_c = \frac{l}{d} \cdot (1 + cos\alpha)$

where α is branch tilt angle (i.e. 90° for a vertical branch, 0° for an horizontal branch). In vertical branches $SR_c = SR$, in horizontal branches $SR_c = 2SR$.

As far as we know this is the first attempt to apply the slenderness ratio to branches. Optimal (safe) branches could be in the range $30 \leq SR_c \leq 70$.

When `treeData` object is filled with branches `length` (not to be confused with `tipD`, the length of branch projection on the ground, from the tree base to branch tip) than SR_c can be computed and plotted:

```
> data(treeData)
> # assign length to branches
> treeData$fieldData <- within(treeData$fieldData,
+ length[3:25] <- c(7, 7, 7, 7, 7, 7, 4, 7, 7, 4, 7, 7, 4, 7, 7, 7, 4, 7, 7, 4, 4, 7, 7)
+ )
> vectors <- treeVectors(treeData)
> SR      <- treeSR(treeData,vectors)
> plot(SR, main = "Branches slenderness ratio", xaxt='n', yaxt = 'n', xlab = "", ylab = "")
```



The 2D plot charts branches azimuth as arrows whose length is SR_c. The longer the arrows the more slender the branch. Arrows pointing inside the red circle are considered to be stable, whereas longer arrows are considered as risky ($SR_c \geq 70$). The plot may be a visual clue on the process of branch pruning selection.

1.6 Tree stabilization

Estimating the coordinates of the centre of mass of a tree is crucial to judge its static stability. The centre of mass of a perfectly balanced tree lies in between its trunk, that is the x and y coordinates of the CM lie inside the $\pi \cdot r^2$ surface where r is the radius of tree base.

The more distant the centre of mass from tree base the higher the constrains the tree poses on the soil through its roots. When concerns about tree stability are raised and the tree needs to be consolidated a proper cabling system has to be put in place. Knowing in advance the direction the tree would fall in case of breakage at its base is necessary to properly engineer the cabling system.

........CONTINUARE CON LA DESCRIZIONE DELLA STABILIZZAZIONE

menzionare come deve essere fatto l'ancoraggio sull'albero e che deve essere periodicamente allargato, magari allegare una foto di cosa succede se viene messo troppo stretto sull'albero.

menzionare che deve essere lasso ma non troppo perche l'albero, se cade, ci si deve appoggiare senza strappi dovuti ad una velocita' eccessiva che puo' prendere se l'ancora e' eccessivamente lassa.

2 Data collection

Data collection to estimation of the centre of mass is carried out in three steps:

1. Field measurements
2. Visual check for correctness of assumptions
3. Collection of correct allometric equation in order to estimate branch and foliage biomass

2.1 Field measurements

A few field measurements are needed to estimate centre of mass position at the stem level and at the branch level. Field data are easily recorded climbing the tree using tree-climbing techniques or by hydraulic platforms. A few instruments are needed including:

- A forestry caliper to measure diameter of logs and branches
- A clinometer, or ipsometer or any other instrument to measure height of branches or logs
- A measuring tape to measure length of branch or log projections on the ground

The stem is ideally sectioned in logs in order to compute their volume and mass. The measurements to be taken on each log include:

- Diameter at the base of the log, in cm
- Diameter at the top of the log, in cm
- Length of the log, in m
- Azimuth of the log, in case it is not vertical, in degrees from North (O° North, 180° South)
- Length of log projection on the ground, from the tree base to the log tip (0 for a vertical stem), in m
- Height above ground of the base of the log, in m
- Log tilt from the horizontal plane (eg a vertical log is tilted by 90°, an horizontal log is tilted by 0°), in degrees (optional)

Each branch contributes to the position of the centre of mass by means of their wooden component and their foliage component. Every part of a tree carrying foliage is considered to as a branch. This definition applies to tree tip as well, although some trees may have lost their tip or have it removed during topping operations. The measurements to be taken on each branch include:

- Diameter at the base of the branch, in cm
- Azimuth of the branch, in degrees, usually measured with a compass (O° North, 180° South)
- Length of branch projection on the ground, from the tree base to the branch tip, in m
- Height above ground of the branch insertion into the stem
- Branch tilt from the horizontal plane (eg a vertical branch is tilted by 90°, an horizontal branch is tilted by 0°), in degrees (optional)

2.2 Visual check for correctness of assumptions

2.2.1 Relative position of centre of masses of branches and logs

The position of the centre of mass of a tree is computed taking into account the centre of mass of each branch and log. Pinpointing the centre of mass along a branch, taking into account branch form factor and the pattern of distribution of leaves biomass along it, would require many more field measures raising the time spent on it and the costs of the sampling.

Since the package aims to help engineering a consolidation system, the centre of mass is by default located at branches or logs tip. This leads to an estimate of the coordinated of tree centre of mass that is further away from the base than the real one. This difference can be regarded as an inherent safety factor.

The package behaviour can be modified in order to let the position branches and logs centre of mass to get nearer to their base. The relative position of the centre of mass of branches and logs can be set as a real number ranging from 0.01 (base) to 1 (tip, the default behaviour). Setting can be done during import of field data using function `importField` and its parameter `bCM` or by using the setter function `setBrancheSRM`.

2.2.2 The density

Log mass is estimated by converting its volume (as measured in the field) to fresh mass. The conversion factor is usually referred to as density. Wood density is usually quite conservative among individual of the same tree species. Density values are commonly found in published literature. The following table (Niklas et al. (2010)) can be a useful resource (density in $\frac{kg}{m^3}$, measured at 50% moisture content):

```
> library(treecm)
> data(Dst)
> print(Dst)
```

```
                       species   group density
1                   Abies alba conifer     545
2                   Abies alba conifer     577
3                Abies balsama conifer     529
4                Abies grandis conifer     449
5                Abies procera conifer     465
6            Agathis vitiensis conifer     673
7       Araucaria angustifolia conifer     689
8   Chaemaecyparis lawsoniana conifer     497
9               Larix decidua conifer     673
10            Larix eurolepis conifer     577
11            Larix kaempferi conifer     609
12               Picea abies conifer     497
13                Picea alba conifer     529
14             Picea omorika conifer     497
15           Picea sitchensis conifer     481
16           Picea sitchensis conifer     529
17            Pinus caribaea conifer     977
18            Pinus contorta conifer     593
19          Pinus holfordiana conifer     513
20               Pinus nigra conifer     609
21               Pinus nigra conifer     705
22            Pinus pinaster conifer     609
23           Pinus ponderosa conifer     561
24             Pinus radiata conifer     577
25             Pinus radiata conifer     641
26             Pinus strobus conifer     433
27           Pinus sylvestris conifer     625
28            Podocarpus sp. conifer     641
```

29	Podocarpus guatemalensis	conifer	657
30	Pseudotsuga menziesii	conifer	625
31	Pseudotsuga menziesii	conifer	673
32	Thuja heterophylla	conifer	545
33	Thuja heterophylla	conifer	593
34	Thuja heterophylla	conifer	609
35	Thuja plicata	conifer	465
36	Aesculus hippocastanum	dicot	657
37	Acacia mollissima	dicot	897
38	Acer psedudoplatanus	dicot	721
39	Afzelia quanzensis	dicot	1137
40	Alnus glutinosa	dicot	675
41	Alstonia boonei	dicot	497
42	Anthocephalus chinensis	dicot	567
43	Aspidosperma sp.	dicot	993
44	Autranella congolensis	dicot	1144
45	Berlinia confusa	dicot	849
46	Betula sp.	dicot	801
47	Brachstegia nigerica	dicot	865
48	Brachylaena hutchinsii	dicot	1153
49	Byrsonima coriacea	dicot	865
50	Calophyllum brasiliense	dicot	817
51	Canarium schweinfurthii	dicot	593
52	Carpinus betulus	dicot	865
53	Cassispourea malasana	dicot	897
54	Castanea sativa	dicot	657
55	Cedrela odorata	dicot	433
56	Celtis sp.	dicot	961
57	Ceratopetalum apetalum	dicot	733
58	Chlorophora excelsa	dicot	817
59	Cordia millenii	dicot	545
60	Cullenia ceylanica	dicot	769
61	Cyanomeria alexandri	dicot	1121
62	Cylicodiscus gabunensis	dicot	1185
63	Dipterocarpus sp.	dicot	929
64	Dipterocarpus acutangulus	dicot	913
65	Dipterocarpus caudiferus	dicot	753
66	Dipterocarpus zeylanicus	dicot	977
67	Drychalanops beccarii	dicot	865
68	Drychalanops keithii	dicot	902
69	Drychalanops lanceolata	dicot	865
70	Entandrophragma angolense	dicot	705
71	Entandrophragma cylindricum	dicot	833
72	Entandrophragma utile	dicot	833
73	Eperua sp.	dicot	1169
74	Erythrophteum sp.	dicot	1362

75	Eucalyptus piluaris	dicot	897
76	Eucalyptus marginata	dicot	1009
77	Eucalyptus microcorys	dicot	1234
78	Eucalyptus paniculata	dicot	1346
79	Eucalyptus versicolor	dicot	1041
80	Eusideroxylon zwageri	dicot	1282
81	Fagus sylvatica	dicot	833
82	Fraxinus excelsior	dicot	801
83	Gmelina arborea	dicot	625
84	Gonystylus macrophyllum	dicot	785
85	Gossweilerodendron balsamiferum	dicot	641
86	Guarca excelsa	dicot	689
87	Guarca thompsonii	dicot	817
88	Heritiera simplicifolia	dicot	753
89	Heritiera simplicifolia	dicot	801
90	Hevea brasiliensis	dicot	865
91	Hopea sengal	dicot	817
92	Khaya anthotheca	dicot	657
93	Khaya grandiflora	dicot	817
94	Khaya ivorensis	dicot	641
95	Khaya nyascia	dicot	705
96	Koordersiodendron pinnatum	dicot	1089
97	Loniciocarpus castillo	dicot	1169
98	Lophira alata	dicot	1292
99	Lovoa trichilioides	dicot	673
100	Maesopsis veminii	dicot	609
101	Mansonia altissima	dicot	801
102	Mora excelsa	dicot	1137
103	Muragne sp.	dicot	689
104	Nauclea diderrichii	dicot	945
105	Nectrandra sp.	dicot	689
106	Newtonia buchaneni	dicot	705
107	Nothofagus sprocera	dicot	561
108	Ocotea rodiaei	dicot	1250
109	Ocotea usambarensis	dicot	769
110	Octomeles sumatrana	dicot	481
111	Olea hochstetteri	dicot	1121
112	Oxystigma oxyphyllum	dicot	801
113	Parashorea sp.	dicot	705
114	Parashorea malaanonan	dicot	641
115	Parashorea tomentelia	dicot	577
116	Peltogyne sp	dicot	1105
117	Pericopsis elata	dicot	977
118	Pipradeniostrum africanum	dicot	849
119	Platanus hybrida	dicot	785
120	Populus canadensis	dicot	529

121	Populus x canescens	dicot	577
122	Populus x canescens	dicot	481
123	Protium decendrum	dicot	801
124	Prunus avium	dicot	753
125	Pseudosindora palustris	dicot	833
126	Pterocarpus angolensis	dicot	881
127	Pterygota bequaertii	dicot	849
128	Pterygota macrocarpa	dicot	705
129	Qualea sp.	dicot	897
130	Quercus sp.	dicot	833
131	Quercus cerris	dicot	929
132	Quercus rubra	dicot	865
133	Ricinodendron rautanenii	dicot	224
134	Salix x alba	dicot	529
135	Salix alba var. coerulea	dicot	513
136	Salix fragilis	dicot	529
137	Sclerocarpa sp.	dicot	657
138	Scottellia coriacea	dicot	849
139	Shorea acuminatissima	dicot	609
140	Shorea faguetiana	dicot	673
141	Shorea gibbosa	dicot	625
142	Shorea guiso	dicot	993
143	Shorea hakeifolia	dicot	689
144	Shorea leptoclados	dicot	545
145	Shorea macrophylla	dicot	449
146	Shorea parviflora	dicot	513
147	Shorea pauciflora	dicot	689
148	Shorea smithiana	dicot	513
149	Shorea superba	dicot	945
150	Shorea superba	dicot	1057
151	Shorea waltonii	dicot	529
152	Staudtia stipitata	dicot	1139
153	Sterculia oblonga	dicot	913
154	Sterculia rhinopetala	dicot	961
155	Swartzia leiocalycine	dicot	1298
156	Symphonia globulifera	dicot	881
157	Syncarpia glomulifera	dicot	1025
158	Tarrietia utilis	dicot	817
159	Tectona grandis	dicot	801
160	Tectona grandis	dicot	817
161	Terminalia amazonica	dicot	961
162	Tieghemelia heckerii	dicot	801
163	Tilia vulgaris	dicot	657
164	Triplochiton scleroxylon	dicot	465
165	Ulmus glabra	dicot	753
166	Ulmus hollandica	dicot	641

```
167                 Ulmus procera   dicot     641
168               Virola koschnyi   dicot     657
169                  Vochvsia sp.   dicot     657
170          Vochysia hondurensis   dicot     577
```

2.3 Finding a correct allometric equation in order to estimate branch and foliage biomass

It is not feasible to weight the branches of a living tree. As a result branch and foliage biomass is estimated using branch diameter at base. Models relating size or biomass to diameter of trees or branches are known as allometric equations. They usually take the form of $Y = a \cdot X^b$ where Y is branch biomass, X is branch diameter, a and b are parameters estimated on a subsample of branches.

When subsampling is not possible one should rely on published allometric equations and feed them to `treecm`. Currently `treecm` ships with three allometric equations:

- `branchBiomassPine`, tested on stone pine trees (not on branches), 40+ cm diameter, returns biomass (dry weight), Cutini et al. (2009)
- `branchBiomassPinePorte`, tested on maritime pine branches, 10- cm diameter, returns biomass (dry weight), Porté et al. (2002)
- `branchBiomassPineASRa`, tested on stone pine branches, 8-16 cm diameter, predominantly from the lower layers of the crown, returns fresh weight

The proper allometric equation to be used must be fed to `treecm` when importing field data using function `importFieldData`, parameter `branchesAllometryFUN`.

We welcome contributions to increase the available list of allometric equations.

Note that one should pick an allometric equation that yields fresh mass of branches in order to get results as closer as possible to the real tree centre of mass. Function `branchBiomassPineASRa` returns fresh weight values for stone pine branches.

3 Correct layout of CSV file

A sample CSV data file is provided in the `data` directory. Function `importFieldData` loads and stores CSV files and along with needed data. CSV files are made up of 9 columns. The first row has to hold column headers. Headers are case sensitive. Each row holds individual log or branch data. Headers include:

1. **code** a simple code assigned to each log or branch (usually Lx for logs, Bx for branches)
2. **azimuth** orientation, ie: compass bearing in degrees
3. **dBase** diameter of log or branch basal section, in cm

4. **dTip** diameter of log or branch tip (always 0 for branches), in cm

5. **length** log length (leave it empty in case of branches), in m

6. **tipD** distance of the tip of the log or branch to tree base (different from branch length when tree stem is not vertical)

7. **height** height of log basal section of height of branch insertion on stem

8. **tilt** log or branch tilt from the horizontal plane (eg a vertical branch is tilted by 90°, an horizontal branch is tilted by 0°), in degrees (optional, only useful to estimate z coordinate of centre of mass)

9. **toBePruned** boolean to simulate branch pruning

There are a few simple rules to be followed in order to layout a correct CSV file, please refer to page 2

4 Contribute!

`treecm` is an ongoing project hosted on GitHub (`https://github.com/mbask/treecm`). Many areas need to be expanded including:

- branch biomass estimation; allometric equations are used to estimate fresh branch and foliage biomass. So far only branch biomass for stone pine and maritime pine have been developed or integrated into the software from published data. We need to expand further the number of species represented, particularly for those species common in urban area such as cedars, magnolias, oaks

- The package does not estimate the position of the centre of mass of tree branches. This position may vary according to foliage mass and its distribution along the branchs, branch tapering, quantity of water in leaves (*ie* shaded or lit leaves) *etc.* The position must be fed to the package during data loading, as the variable `brancheSRM`. Although going for the safe road, setting a branch centre of mass position on its tip may not be sufficiently precise should one assess wood quality as a function of load balance. Work is under way in order to to model branch load balance

- As far as postion of centre of mass il logs, the package does not tell branches and logs apart. The position of CM in logs follows branches CM position settings, though not realistic.

References

Cutini, A. and Hajny, M. and Gugliotta, O. and Manetti, M. and Amorini, E. 2009, Effetti della struttura del popolamento sui modelli di stima del volume e della biomassa epigea (Pineta di Castelfusano - Roma) *Forest@*, **6**, 75–84 la Marca, O. 2004, *Elementi di dendrometria.* Patron Editore (Bologna), p. 119

Niklas, K. J. and Spatz, H.-C., 2010, Worldwide correlations of mechanical properties and green wood density *American Journal of Botany*, **97**, 1587–1594

Porté, A. and Trichet, P. and Bert, D. and Loustau, D. 2002, Allometric relationships for branch and tree woody biomass of Maritime pine (*Pinus pinaster* Ait.) *Forest Ecology and Management*, **158**, 71–83

Mattheck, C. and Breloer, H., 1995, *The Body Language of Trees: A Handbook for Failure Analysis (Research for Amenity Trees).* HMSO (London).