Handbook of Broadleaf.Korean.pine.LAI

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Leaf Area Index (LAI) refers to half of the total leaf area per unit horizontal ground area, and it is one of the most commonly used parameters for plant canopy structure. Our team has proposed a method for estimating the leaf area index of multi-layer forests based on hierarchical Thiessen polygons. Compared with traditional LAI estimation methods based on formulas, this method can estimate the under-canopy leaf area index of each tree in the stand through Thiessen polygons. On this basis, it can more accurately calculate several canopy structure parameters related to LAI at any point in the stand, including local leaf area index, standard deviation of local leaf area index, contribution rate of various tree species to local leaf area index, and vertical structure characteristics of leaf area index, etc.

Our team has applied the method of estimating the leaf area index of multi-layer forests based on hierarchical Thiessen polygons to the estimation of LAI in broad-leaved Korean pine forests, and developed the R package **Broadleaf.Korean.pine.LAI**.

Dependencies

This package depends on ape, sp, sf, raster, grDevices, rgeos, gstat, tcltk, ggplot2, plot3D, deldir, grDevices, and stats. Please install them first before running.

Installation Method of the Package

library(devtools);install_github("DuXinChina/Broadleaf.Korean.pine.LAI/Broadleaf.Korean.pine.LAI")

1 Demonstration of sample data

The sample data are virtual data, representing a 50m × 50m plot that contains information on the spatial coordinates, diameter at breast height (DBH), and tree height of four tree species: Acer mono, Tilia amurensis, Abies fabri, and Pinus koraiensis. Based on tree height, the broad-leaved Korean pine forest is divided into different layers. Specifically, the understory layer consists of trees with a height less than 10m; the sub-canopy layer includes trees with a height ranging from 10m to 16m; the main canopy layer comprises trees with a height of 16m to 30m; and the emergent layer consists of trees with a height greater than 30m. In the virtual data, the emergent layer contains 2 Pinus koraiensis, distributed randomly. The main canopy layer includes 15 Pinus koraiensis, 10 Abies fabri, 10 Tilia amurensis, and 5 Acer mono, all of which are randomly distributed. The sub-canopy layer contains 50 Acer mono, showing an aggregated distribution with 25 individuals centered at (10, 40) and another 25 centered at (40, 10). The understory layer includes 20 individuals of each of the four tree species, with each species exhibiting an aggregated distribution at a small scale and a random distribution at a large scale. In the emergent layer, the DBH of trees is greater than 60cm; in the main canopy layer, the DBH ranges from 30cm to 60cm; in the sub-canopy layer, the DBH is 10cm to 30cm; and in the understory layer, the DBH is less than 10cm. In the data, columns x and y represent the horizontal coordinates of the trees, DBH stands for diameter at breast height, H denotes tree height, and the Species column indicates the names of the tree species. HS *Pinus koraiensis*, YS *Picea asperata*, LS *Abies fabri*, ZD *Tilia amurensis*, KD *Tilia mandshurica*, MGL *Quercus mongolica*, SQL *Fraxinus mandshurica*, HTQ *Juglans mandshurica*, HBL *Phellodendron amurense*, SMQ *Acer mono*, QKQ *Acer tegmentosum*, HKQ *Acer ukurunduense*, JSQ *Acer pseudosieboldianum*, NJQ *Acer triflorum*, BNQ *Acer mandshuricum*, CY *Ulmus davidiana*、BH *Betula platyphylla*, HH *Maackia amurensis*, FH *Betula costata*, LYY *Ulmus laciniata*, QT others species.

```
data = Broadleaf.Korean.pine.LAI::b
print(data[1:50,])
```

```
##             x           y      DBH  H Species
## 1   33.4288480 18.9819806 65.58075 35      HS
## 2    6.4346078 42.0391756 66.18077 35      HS
## 3   18.1460637 19.2660497 52.26441 25      HS
## 4   27.5928278 13.8968076 32.36649 25      HS
## 5    6.1081642 25.6396705 35.55580 25      HS
## 6   39.5111778  5.1855691 53.03717 25      HS
## 7   18.2991147 36.4641006 31.79671 25      HS
## 8   25.6670756  4.6233300 31.56699 25      HS
## 9   25.2746910  5.0032010 34.37393 25      HS
## 10 11.1674790  8.0279473 58.85923 25      HS
## 11 10.9212414 11.5923407 35.49268 25      HS
## 12 22.6771733 12.8692340 50.35140 25      HS
## 13  3.1528245 40.5892981 40.74983 25      HS
## 14 48.9035375 10.3960484 43.53175 25      HS
## 15 44.4565091 36.6393705 30.29293 25      HS
## 16 18.4087182 19.8480956 34.42979 25      HS
## 17 37.7821442 18.2801837 38.51658 25      HS
## 18 10.2223582  0.3512422 35.39618 25      LS
## 19 23.3121148  6.1817106 40.81871 25      LS
## 20  3.7540585 32.3250375 33.63011 25      LS
## 21 28.3364101  6.5744882 39.98553 25      LS
## 22  6.8510692  9.6053103 54.61050 25      LS
## 23 33.3752221 36.7657443 34.22770 25      LS
## 24 44.9338280  0.6791399 56.57313 25      LS
## 25  1.5318491 24.5214906 34.45361 25      LS
## 26 40.2367382 11.2009961 58.90365 25      LS
## 27 16.3113690 25.0485350 48.07340 25      LS
## 28 31.4198530  6.2785452 52.08889 25      ZD
## 29 46.0771567 27.8802443 51.48180 25      ZD
## 30  0.2149013 46.6323809 59.69902 25      ZD
## 31 48.3191063 30.0955467 52.97271 25      ZD
## 32 25.6461456  8.1469459 30.97305 25      ZD
## 33 37.0948580 34.3532822 45.91319 25      ZD
## 34 15.7041204 49.4823055 57.68552 25      ZD
## 35  9.0926424 24.8328917 45.38274 25      ZD
## 36 10.1880918 36.0375070 58.16464 25      ZD
## 37  6.6190212 46.7338556 44.88035 25      ZD
## 38 27.8663572 22.0768596 51.73629 25     SMQ
## 39 15.3366110 16.2149379 42.41976 25     SMQ
## 41 27.9685288 10.7013771 31.98887 25     SMQ
## 42 30.4606082  4.4862904 31.22400 25     SMQ
## 43 27.4182794  5.0037950 20.83706 15     SMQ
## 44 44.4396113 28.8874433 10.62590 15     SMQ
## 45 34.8701260 10.9891497 26.20909 15     SMQ
## 46 29.3663570 24.8532922 21.75096 15     SMQ
## 47 39.0940332 21.3669462 14.55820 15     SMQ
## 48 37.8461923  0.8798485 25.23866 15     SMQ
## 49 40.8974968 15.1046335 15.41021 15     SMQ
## 50 43.7170631 12.4452323 24.45391 15     SMQ
## 52 34.7943280 15.7893710 13.23042 15     SMQ
```

2 Examples

2.1 LAI.single(a, b, r)

2.1.1 Introduction to functions:

Based on traditional methods, calculate the leaf area index in a circular area with a certain radius centered at any point in the broad-leaved Korean pine forest, and give the proportion of different tree species in the leaf area index, as well as the proportion of the leaf area index of coniferous tree species and broad-leaved tree species.

2.1.2 Parameter meanings:

a — coordinates of the point where the leaf area index needs to be calculated;

b — information on the coordinates, tree species, DBH (diameter at breast height) and tree height of the trees in the plot;

r — radius of the circle centered at the point.

2.1.3 Example:

Calculate the leaf area in a circle with (25,25) as the center and 5m as the radius.

```
a=matrix(c(25,25),1,2)
colnames(a)=c("x","y")
a
```

```
##       x  y
## [1,] 25 25
```

```
b=Broadleaf.Korean.pine.LAI::b[,-4]
head(b)
```

```
##           x          y      DBH Species
## 1 33.428848 18.981981 65.58075      HS
## 2  6.434608 42.039176 66.18077      HS
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
```

```
Broadleaf.Korean.pine.LAI::LAI.single(a=a,b=b,r=5)
```

```
## $LAI
## [1] 12.23283
##
## $Species_LAI
##      HS_LAI LS_LAI YS_LAI ZD_LAI KD_LAI MGL_LAI SQL_LAI HTQ_LAI HBL_LAI
## [1,]      0      0      0      0      0       0       0       0       0
##       SMQ_LAI QKQ_LAI HKQ_LAI JSQ_LAI NJQ_LAI BNQ_LAI CY_LAI BH_LAI HH_LAI
## [1,] 12.23283       0       0       0       0       0      0      0      0
##      FH_LAI LYY_LAI QT_LAI
## [1,]      0       0      0
##
## $N_B_LAI
##      Needles_LAI Broadleaf_LAI N_L_percent B_L_percent
## [1,]           0      12.23283           0         100
```

Total leaf area index is 12.23283, leaf area of Acer mono is 12.23283, leaf area of broad-leaved tree species is 12.23283, and the proportion of broad-leaved species is 100%.

2.2 LAI.mult(a, b, r)

2.2.1 Introduction to functions: Calculate the leaf area index within circular regions of a certain radius centered at multiple points in the broad-leaved Korean pine forest, including the leaf area indices of coniferous and broad-leaved tree species, as well as the respective proportions of coniferous and broad-leaved areas.

2.2.2 Parameter meanings:

a — coordinates of multiple points for which the leaf area index needs to be calculated

b — information on the coordinates, tree species, DBH (diameter at breast height), and tree height of the trees in the plot

r — radius of the circle centered at the points

2.2.3 Example:

Calculate the leaf area index, coniferous leaf area index, broad-leaved leaf area index, and the proportions of leaf area indices of coniferous and broad-leaved tree species at multiple sample points.

```
a=matrix(runif(10,5,45),5,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
a
```

```
##          x         y
## 1 29.53370 41.351418
## 2 26.45977 18.283944
## 3 40.23980  9.167982
## 4 43.93770 33.046110
## 5 27.85152 29.473093
```

```
b=Broadleaf.Korean.pine.LAI::b[,-4]
head(b)
```

```
##           x          y      DBH Species
## 1 33.428848 18.981981 65.58075      HS
## 2  6.434608 42.039176 66.18077      HS
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
```

```
library()
Broadleaf.Korean.pine.LAI::LAI.mult(a=a,b=b,r=5)
```

```
## Warning: 程序包'gstat'是用R版本4.4.3 来建造的
```

```
## Warning: 程序包'ggplot2'是用R版本4.4.3 来建造的
```

```
## $LAI
##          x          y       LAI
## 1 29.53370 41.351418  3.626077
## 2 26.45977 18.283944 13.746109
## 3 40.23980  9.167982 28.233053
## 4 43.93770 33.046110  3.702132
## 5 27.85152 29.473093  4.688695
##
## $B_N_LAI
##          x          y Needles_LAI Broadleaf_LAI N_L_percent B_L_percent
## 1 29.53370 41.351418   0.2015665      3.424511    5.558803    94.44120
## 2 26.45977 18.283944   3.0866765     10.659432   22.454911    77.54509
## 3 40.23980  9.167982  14.4212079     13.811845   51.079167    48.92083
## 4 43.93770 33.046110   2.6076979      1.094434   70.437740    29.56226
## 5 27.85152 29.473093   0.0000000      4.688695    0.000000   100.00000
```

2.3 Plot.LAI.Krig (minx, maxx, miny, maxy, b, seq, r)

2.3.1 Introduction to functions:

Draw the Kriging interpolation map of leaf area index in broad-leaved Korean pine forests. Calculate the semi-variogram of leaf area index in broad-leaved Korean pine forests.

2.3.2 Parameter meanings:

minx — minimum abscissa for drawing the Kriging interpolation map

maxx — maximum abscissa for drawing the Kriging interpolation map

miny — minimum ordinate for drawing the Kriging interpolation map

maxy — maximum ordinate for drawing the Kriging interpolation map

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

seq — spatial resolution for drawing the Kriging map

r — radius of the circle centered at the point

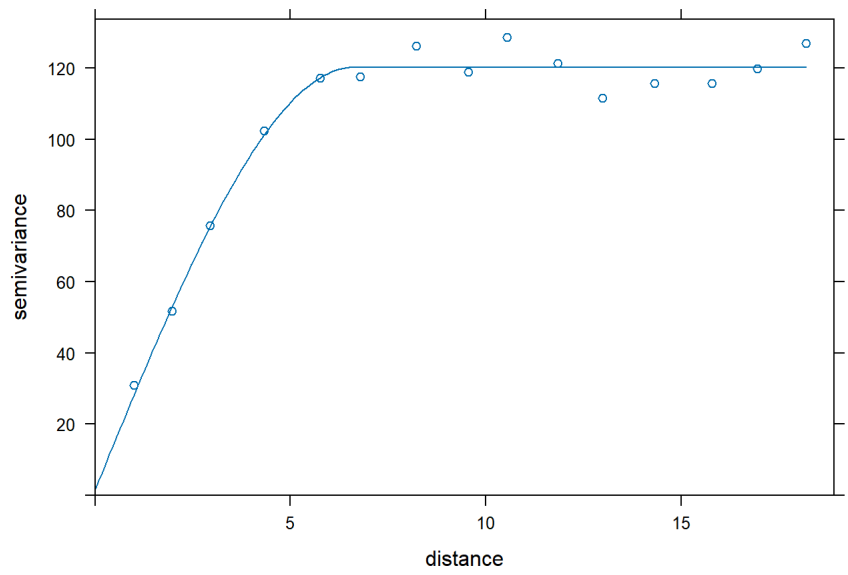
2.3.3 Example:

```
b=Broadleaf.Korean.pine.LAI::b[,-4]
head(b)
```

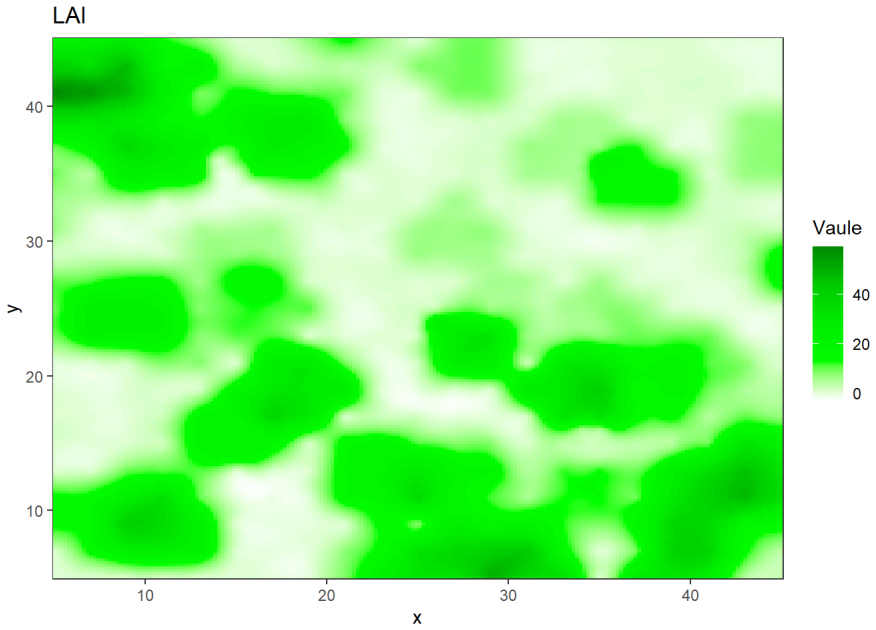
```
##          x          y      DBH Species
## 1 33.428848 18.981981 65.58075      HS
## 2  6.434608 42.039176 66.18077      HS
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
```

```
p=Broadleaf.Korean.pine.LAI::Plot.LAI.Krig(5,45,5,45,b=b,seq=20,r=3)
```

```
##   model     psill    range
## 1   Nug   1.77716 0.000000
## 2   Sph 118.41951 6.636184
```



```
## [1] "Coefficient_of_Determination= 0.976014299370735"
## [using ordinary kriging]
```



2.4 Standing_Forest_LAI(minx, maxx, miny, maxy, b)

2.4.1 Introduction to functions:

Calculate the leaf area index of the entire broad-leaved Korean pine forest stand, and provide the quantity and proportion of leaf area index for different tree species, as well as the quantity and proportion of leaf area index for coniferous and broad-leaved tree species.

2.4.2 Parameter meanings:

minx — minimum boundary of the plot's abscissa for leaf area index calculation

maxx — maximum boundary of the plot's abscissa for leaf area index calculation

miny — minimum boundary of the plot's ordinate for leaf area index calculation

maxy — maximum boundary of the plot's ordinate for leaf area index calculation

b — information on tree distribution

2.4.3 Example:

```
b=Broadleaf.Korean.pine.LAI::b[,-4]
head(b)
```

```
##           x          y      DBH Species
## 1 33.428848 18.981981 65.58075      HS
## 2  6.434608 42.039176 66.18077      HS
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
```

```
Broadleaf.Korean.pine.LAI::Standing_Forest_LAI(minx=5,maxx=45,miny=5,maxy=45,b)
```

```
## $LAI
## [1] 11.25676
##
## $Species_LAI
##        HS_LAI   LS_LAI YS_LAI   ZD_LAI KD_LAI MGL_LAI SQL_LAI HTQ_LAI HBL_LAI
## [1,] 3.948259 1.242444      0 1.352644      0       0       0       0       0
##       SMQ_LAI QKQ_LAI HKQ_LAI JSQ_LAI NJQ_LAI BNQ_LAI CY_LAI BH_LAI HH_LAI
## [1,] 4.713409       0       0       0       0       0      0      0      0
##      FH_LAI LYY_LAI QT_LAI
## [1,]      0       0      0
##
## $N_B_LAI
##      Needles_LAI Broadleaf_LAI N_L_percent B_L_percent
## [1,]    5.190703      6.066053     46.11189     53.88811
```

The stand leaf area index is 11.896. The leaf area index of Pinus koraiensis (HS) is 3.948; the leaf area index of Abies fabri (LS) is 1.242; the leaf area index of Tilia amurensis (ZD) is 1.353; the leaf area index of Acer mono (SMQ) is 5.352. The leaf area index of coniferous tree species is 5.191; the leaf area index of broad-leaved tree species is 6.705. The proportion of leaf area index of coniferous tree species is 43.636%; the proportion of leaf area index of broad-leaved tree species is 56.364%.

2.5 LSD_LAI(a, b, r, Lr)

2.5.1 Introduction to functions:

After calculating the leaf area index of the broad-leaved Korean pine forest with the area of a circle with a certain radius as the resolution, this function calculates the local standard deviation of the leaf area index within a circle with a certain radius centered at a specific point. Under normal circumstances, the leaf area index at forest edges and at the intersections of canopies of large and small trees has a relatively large local standard deviation.

2.5.2 Parameter meanings:

a — coordinates of the point where the local standard deviation of the leaf area index needs to be calculated

b — information on tree distribution, as well as DBH (diameter at breast height) and tree height

r — radius of the circle used for calculating the leaf area index within the forest

Lr — radius of the circle used for calculating the local standard deviation of the leaf area index at the point

2.5.3 Example:

```
a=data.frame(28,25)
colnames(a)=c("x","y")
a
```

```
##    x  y
## 1 28 25
```

```
b=Broadleaf.Korean.pine.LAI::b[,-4]
head(b)
```

```
##           x          y      DBH Species
## 1 33.428848 18.981981 65.58075      HS
## 2  6.434608 42.039176 66.18077      HS
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
```

```
result=Broadleaf.Korean.pine.LAI::LSD_LAI(a=a,b=b,r=3,Lr=1.5)
result
```

```
##    x  y  LSD_LAI
## 1 28 25 13.82343
```

2.6 LSD_LAI_mult(a, b, r, Lr)

2.6.1 Introduction to functions:

Calculate the local standard deviation of the leaf area index for multiple points.

2.6.2 Parameter meanings:

a — coordinates of the points where the local standard deviation of the leaf area index needs to be calculated

b — information on tree distribution, as well as DBH (diameter at breast height) and tree height

r — radius of the circle used for calculating the leaf area index within the forest

Lr — radius of the circle used for calculating the local standard deviation of the leaf area index at the points

2.6.3 Example:

```
a=matrix(runif(10,5,45),5,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
a
```

```
##           x        y
## 1 11.556327 32.21573
## 2 23.206421 44.60338
## 3 24.105158 21.25145
## 4 37.086277 22.90917
## 5  9.315198 25.32244
```

```
b=Broadleaf.Korean.pine.LAI::b[,-4]
head(b)
```

```
##           x         y      DBH Species
## 1 33.428848 18.981981 65.58075      HS
## 2  6.434608 42.039176 66.18077      HS
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
```

```
result=Broadleaf.Korean.pine.LAI::LSD_LAI_mult(a=a,b=b,r=3,Lr=1.5)
formattable::formattable(result)
```

```
## Warning in attr(x, "align"): xfun::attr()不再有用。
## 请用'xfun::attr2()'。
## 见help("Deprecated")
```

x	y	LSD_LAI
11.556327	32.21573	5.532842
23.206421	44.60338	5.116984
24.105158	21.25145	7.476386
37.086277	22.90917	2.214695
9.315198	25.32244	4.153586

2.7 Plot.LSD_LAI.Krig(minx, maxx, miny, maxy, b, seq, r, Lr)

2.7.1 Introduction to functions:

Draw the Kriging interpolation map of the local standard deviation of leaf area index in broad-leaved Korean pine forests. Calculate the semi-variogram of the local standard deviation of leaf area index in broad-leaved Korean pine forests.

2.7.2 Parameter meanings:

minx — minimum abscissa for drawing the Kriging interpolation map

maxx — maximum abscissa for drawing the Kriging interpolation map

miny — minimum ordinate for drawing the Kriging interpolation map

maxy — maximum ordinate for drawing the Kriging interpolation map

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

seq — spatial resolution for drawing the Kriging map

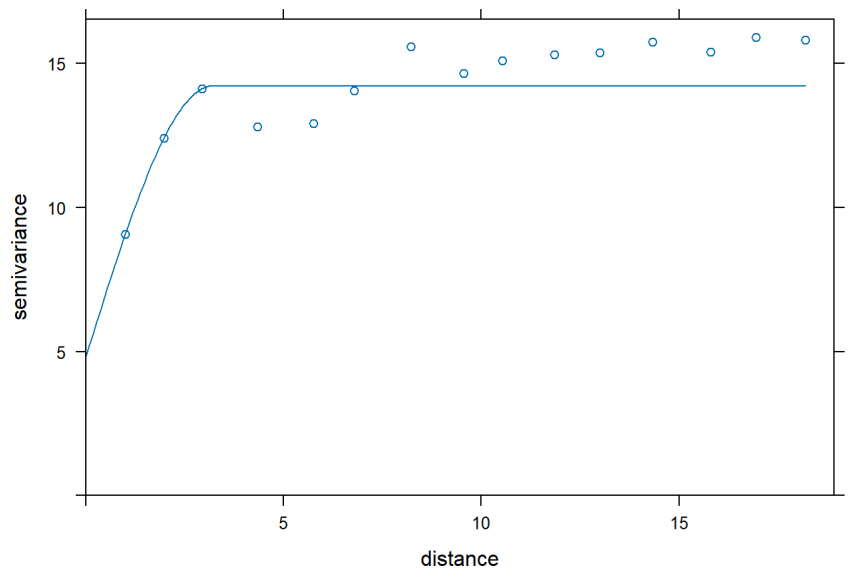
r — radius of the circle centered at the point when calculating the stand leaf area index

Lr — radius of the sampling circle when calculating the local standard deviation of the stand leaf area index

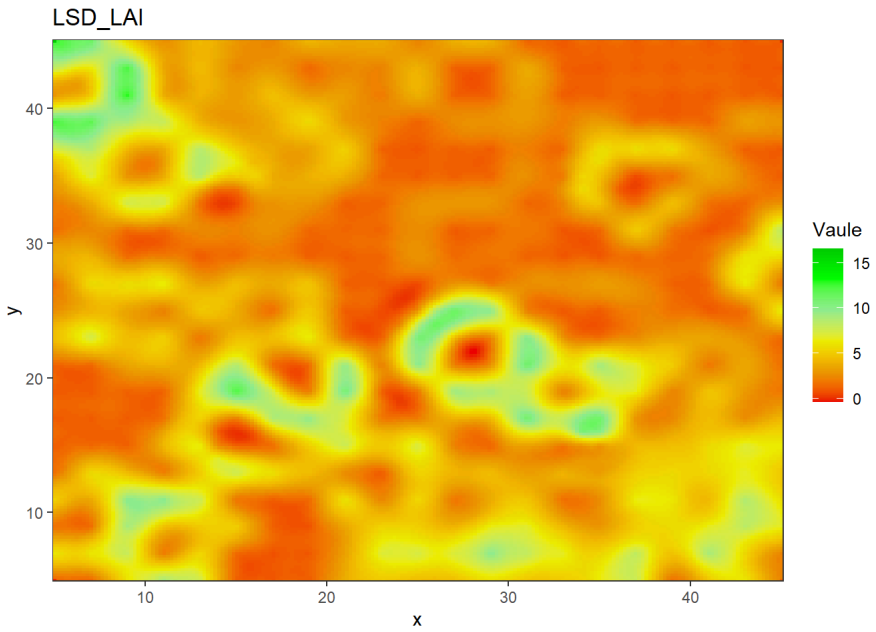
2.7.3 Example:

```
p=Broadleaf.Korean.pine.LAI::Plot.LSD_LAI.Krig(minx=5,maxx=45,miny=5,maxy=45,b=b,seq=20,r=3,Lr=1)
```

```
##   model    psill    range
## 1   Nug 4.822950 0.000000
## 2   Sph 9.399724 3.202621
```



```
## [1] "Coefficient_of_Determination= 0.620507794377322"
## [using ordinary kriging]
```



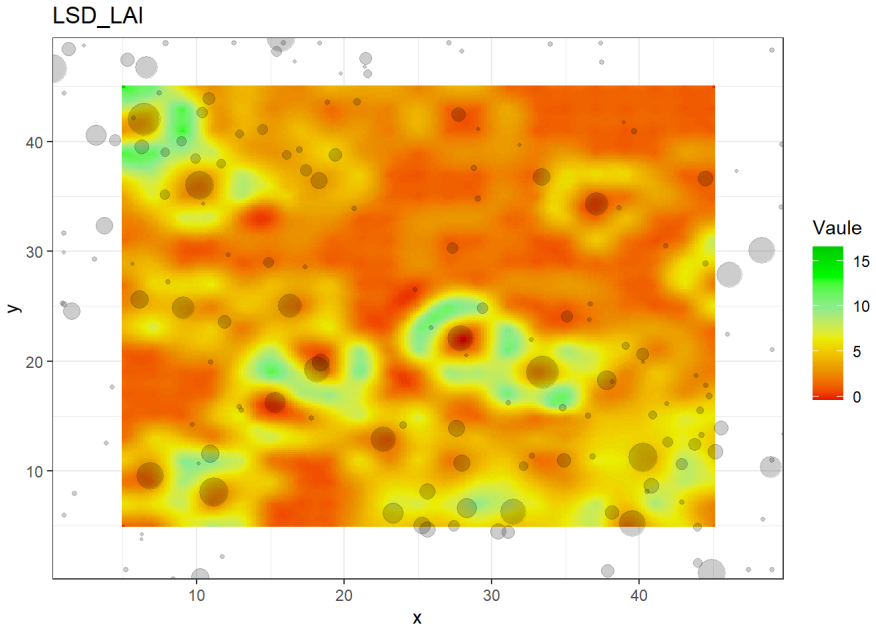

```
p1=p+geom_vline(xintercept = c(5,45),linetype=2)+geom_hline(yintercept =c(5,45),linetype=2)
p1=p+scale_x_continuous(expand= c(0, 5))+scale_y_continuous(expand= c(0, 5))
```

```
## Scale for x is already present.
## Adding another scale for x, which will replace the existing scale.
## Scale for y is already present.
## Adding another scale for y, which will replace the existing scale.
```

```
p2=p1+geom_point(data=b,aes(x=x,y=y),size=b$DBH/8,col="grey4",alpha=0.2)+scale_x_continuous(expand= c(0, 0))+scale_y_continuous
(expand= c(0, 0))
```

```
## Scale for x is already present.
## Adding another scale for x, which will replace the existing scale.
## Scale for y is already present.
## Adding another scale for y, which will replace the existing scale.
```

```
p2
```



2.8 Voronoi.LAI(minx, maxx, miny, maxy, boundary, b, r)

2.8.1 Introduction to functions:

Calculate the leaf area index under each tree in the forest land (single forest layer) based on the Voronoi diagram method.

2.8.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the plot boundary buffer zone

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points. Sample points will be added at positions where there are no trees in the stand to prevent excessively large Voronoi polygons centered on trees.

2.8.3 Example:

```
b=Broadleaf.Korean.pine.LAI::b
b=subset(b,b$H<10)
b=b[,-4]
head(b)
```

```
##           x        y      DBH Species
## 93 39.64364 40.98114 9.934820      LS
## 94 49.61224 34.02107 8.551500      LS
## 95 46.58680 37.33223 5.193316      LS
## 96 49.00000 48.30858 8.632041      LS
## 97 29.08525 41.11792 6.165639      LS
## 98 29.02066 34.80735 9.694307      LS
```

```
result=Broadleaf.Korean.pine.LAI::Voronoi.LAI(minx=0,maxx=50,miny=0,maxy=50,boundary=5,b=b,r=2)
```

```
## deldir 2.0-4      Nickname: "Idol Comparison"
```

```
##
##      The syntax of deldir() has changed since version
##      0.0-10.  Read the help!!!.
```

```
formattable::formattable(result)
```

```
## Warning in attr(x, "align"): xfun::attr()不再有用。
## 请用'xfun::attr2()'。
## 见help("Deprecated")
```

	x	y	DBH	Species	deldir_area	LAI
1131	49.0000000	1.0000000	9.106646	HS	6.351193	3.5706003
1141	48.3429683	5.6185863	7.605254	HS	10.526040	1.5490501
1151	40.5465709	8.1345473	8.666798	HS	8.673114	2.3881160
1161	49.0000000	11.0004526	9.061282	HS	9.023746	2.4902250
1171	6.2794533	4.2384272	5.919919	HS	6.923454	1.4886705
1181	1.0000000	5.9588289	7.419849	HS	11.101522	1.4038545
1191	3.8418102	12.5395119	6.657954	HS	9.804799	1.3034956
1201	1.7257937	7.9206185	8.538493	HS	9.751063	2.0668947
1211	41.8513062	16.1607322	7.772832	HS	10.233926	1.6581341
1221	40.2428301	19.8903321	5.406923	HS	10.203823	0.8556186
1231	36.5047511	15.0316257	9.628256	HS	9.955278	2.5225137
1241	36.7982127	11.3218356	9.553490	HS	11.079585	2.2344182
1251	31.1297617	16.2011382	8.440440	HS	9.774625	2.0187643
1261	36.6997820	25.2196392	7.903824	HS	8.563030	2.0432608
1271	32.7186422	11.4235729	9.530176	HS	11.262486	2.1883197
1281	28.2869781	20.5159761	6.201615	HS	9.819162	1.1429130
1291	17.7794649	14.8297948	8.094559	HS	10.289700	1.7762754
1301	13.0119315	15.5301695	8.087604	HS	8.745888	2.0865342
1311	12.8823991	15.8329528	8.933832	HS	6.865428	3.1892889
1321	10.1283477	10.6649023	5.769270	HS	10.686881	0.9199679
931	39.6436424	40.9811422	9.934820	LS	6.717356	1.8920034
941	49.6122418	34.0210738	8.551500	LS	10.466771	0.8900805

	x	y	DBH	Species	deldir_area	LAI
951	46.5867969	37.3322312	5.193316	LS	9.450425	0.3508748
961	49.0000000	48.3085792	8.632041	LS	9.759273	0.9733234
971	29.0852543	41.1179223	6.165639	LS	10.572632	0.4475085
981	29.0206565	34.8073513	9.694307	LS	9.591146	1.2595182
991	28.7770563	37.6178602	9.306080	LS	10.123716	1.0964011
1001	38.6189406	33.9430026	8.822112	LS	11.587956	0.8575519
1011	45.9365553	22.4422532	6.603459	LS	12.710238	0.4290834
1021	36.6124557	23.8282281	6.482322	LS	8.639266	0.6075241
1031	42.8625806	7.1329634	8.337840	LS	10.265588	0.8611864
1041	32.6357700	21.9731506	7.542603	LS	10.991263	0.6535290
1051	11.7305549	2.2269401	6.781676	LS	9.651604	0.5971063
1061	5.1875622	1.0000000	8.702628	LS	7.232443	1.3357205
1071	8.4335608	0.1246017	9.224902	LS	10.791388	1.0100682
1081	6.2689242	3.7764784	5.028092	LS	6.016010	0.5154787
1091	49.7399440	13.3581418	5.351386	LS	10.095259	0.3495082
1101	44.1681187	13.2980574	9.975786	LS	10.572373	1.2124097
1111	49.0000000	21.0523839	7.792711	LS	10.145719	0.7574857
1121	47.4105839	1.0000000	8.252535	LS	7.036175	1.2299673
1331	3.0805107	29.2901996	8.609461	ZD	7.397749	3.4315899
1341	0.9071648	25.2446763	8.010450	ZD	7.861971	2.8704561
1351	1.0000000	29.8599316	5.312565	ZD	7.944869	1.4531956
1361	1.0000000	31.6702470	8.310919	ZD	8.341543	2.8729964
1371	18.3311714	49.0000000	7.540457	ZD	7.238526	2.8247306
1381	21.4111116	46.7843710	5.504480	ZD	9.344123	1.3092564
1391	18.8694693	43.5405025	8.373520	ZD	8.301285	2.9225026
1401	19.7880615	46.1762995	5.829197	ZD	7.549090	1.7794798
1411	7.4560338	44.4200915	8.199286	ZD	8.359500	2.8042480
1421	16.6670340	47.2940320	6.212923	ZD	8.655479	1.7221941
1431	12.5297550	49.0000000	8.027718	ZD	9.927875	2.2811416
1441	15.8983970	49.0000000	7.926028	ZD	9.152429	2.4234644
1451	38.9231748	41.7665160	6.291640	ZD	5.676560	2.6804741
1461	37.4657599	47.2459319	8.682012	ZD	7.404217	3.4758700
1471	49.6668905	39.7330850	8.203196	ZD	11.848520	1.9800244
1481	31.8817342	39.6527677	5.795613	ZD	9.619317	1.3834013
1491	5.6448613	28.8535785	5.703050	ZD	9.278930	1.3969576
1501	4.2739190	17.6424662	6.565414	ZD	11.075167	1.4727726
1511	10.9522913	19.9384604	9.095775	ZD	11.712855	2.3707069
1521	9.6877684	14.2428889	6.697895	ZD	11.577869	1.4555159
1531	7.8820318	49.0000000	9.916860	SMQ	9.756934	4.7011145
1541	1.0000000	44.4448761	6.899585	SMQ	9.666726	2.5786428
1551	2.3695873	48.7241619	6.060310	SMQ	10.536778	1.9022829
1561	5.6845312	42.1728318	7.417518	SMQ	11.126609	2.5301780
1571	20.6701393	33.8747094	8.585438	SMQ	9.558668	3.7658803
1581	17.3413093	28.6130006	7.200311	SMQ	9.952959	2.6906948
1591	24.7963305	26.5485412	6.546525	SMQ	10.111355	2.2569088
1601	25.8814922	23.0839561	7.570419	SMQ	10.975876	2.6544254
1611	38.1404212	18.1701050	7.064143	SMQ	8.354546	3.1042401
1621	44.4997075	17.7732229	8.575503	SMQ	11.831227	3.0366083
1631	41.8010491	30.4660159	8.362883	SMQ	9.328978	3.6919476

	x	y	DBH	Species	deldir_area	LAI
1641	43.8052430	18.7144681	7.256104	SMQ	9.298452	2.9177030
1651	27.9742202	48.2190508	7.243758	SMQ	8.766556	3.0858836
1661	27.1037613	49.0000000	8.991668	SMQ	7.925497	4.9089445
1671	33.9898945	48.8409792	8.534445	SMQ	11.451778	3.1120164
1681	37.3406029	49.0000000	6.711967	SMQ	9.818730	2.4237531
1691	10.4386867	34.3300143	5.309605	SMQ	9.887581	1.6231128
1701	8.0524403	27.1832789	9.161863	SMQ	8.734993	4.5966489
1711	1.0000000	25.2146483	9.680147	SMQ	2.613125	16.8545260
1721	12.1497107	29.6801073	6.772546	SMQ	10.718650	2.2540481

2.9 Plot.Voronoi.LAI(minx, maxx, miny, maxy, boundary, b, r)

2.9.1 Introduction to functions:

Calculate the leaf area index at each position in the forest land of a single layer within a single-layer forest or a multi-layer forest based on the Voronoi diagram method, and plot the result.

2.9.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the plot boundary buffer zone

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

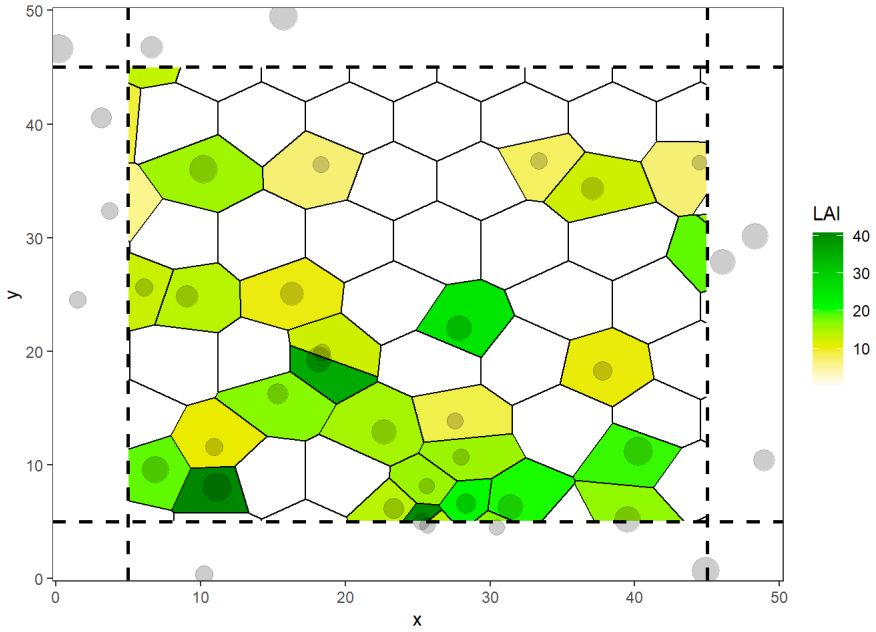
r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points. Sample points will be added at positions where there are no trees in the stand to prevent excessively large Voronoi polygons centered on trees.

2.9.3 Example:

```
b=Broadleaf.Korean.pine.LAI::b
b=subset(b,b$H>20 & b$H<30)
b=b[,-4]
head(b)
```

```
##           x          y      DBH Species
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
## 7 18.299115 36.464101 31.79671      HS
## 8 25.667076  4.623330 31.56699      HS
```

```
p=Broadleaf.Korean.pine.LAI::Plot.Voronoi.LAI(minx=0,maxx=50,miny=0,maxy=50,boundary=5,b=b,r=3.5)
p1=p+geom_point(data=b,aes(x=x,y=y),size=b$DBH/8,col="grey4",alpha=0.2)
p1
```



2.10 Single.point.Voronoi.LAI(minx, maxx, miny, maxy, boundary, a, b, r)

2.10.1 Introduction to functions:

Calculate the leaf area index at any single point in the forest land of a single layer within a single-layer forest or a multi-layer forest based on the Voronoi diagram method.

2.10.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the plot boundary buffer zone

a — coordinates of the point for which the leaf area index needs to be calculated

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points. Sample points will be added at positions where there are no trees in the stand to prevent excessively large Voronoi polygons centered on trees.

2.10.3 Example:

```
a=matrix(runif(2,5,45),1,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
a
```

```
##          x        y
## 1 27.30451 25.69837
```

```
b=Broadleaf.Korean.pine.LAI::b
b=subset(b,b$H>20 & b$H<30)
b=b[,-4]
head(b)
```

```
##           x          y      DBH Species
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
## 7 18.299115 36.464101 31.79671      HS
## 8 25.667076  4.623330 31.56699      HS
```

```
result=Broadleaf.Korean.pine.LAI::Single.point.Voronoi.LAI(minx=0,maxx=50,miny=0,maxy=50,boundary=5,a=a,b=b,r=3.5)
formattable::formattable(result)
```

```
## Warning in attr(x, "align"): xfun::attr()不再有用。
## 请用'xfun::attr2()'。
## 见help("Deprecated")
```

	pointx	treex	treey	Species	LAI
381	27.30451	27.86636	22.07686	SMQ	25.00448

2.11 mult.point.Voronoi.LAI(minx, maxx, miny, maxy, boundary, a, b, r)

2.11.1 Introduction to functions:

Calculate the leaf area index at any multiple points in the forest land of a single layer within a single-layer forest or a multi-layer forest based on the Voronoi diagram method.

2.11.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the plot boundary buffer zone

a — coordinates of the points for which the leaf area index needs to be calculated

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points. Sample points will be added at positions where there are no trees in the stand to prevent excessively large Voronoi polygons centered on trees.

2.11.3 Example:

```
set.seed(100)
a=matrix(runif(40,5,45),20,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
head(a)
```

```
##           x        y
## 1 17.310644 26.43245
## 2 15.306900 33.43215
## 3 27.092897 26.53395
## 4  7.255326 34.95889
## 5 23.741971 21.80406
## 6 24.350829 11.85681
```

```
b=Broadleaf.Korean.pine.LAI::b
b=subset(b,b$H>20 & b$H<30)
b=b[,-4]
head(b)
```

```
##           x          y      DBH Species
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
## 7 18.299115 36.464101 31.79671      HS
## 8 25.667076  4.623330 31.56699      HS
```

```
result=Broadleaf.Korean.pine.LAI::mult.point.Voronoi.LAI(minx=0,maxx=50,miny=0,maxy=50,boundary=5,a=a,b=b,r=3.5)
formattable::formattable(result)
```

```
## Warning in attr(x, "align"): xfun::attr()不再有用。
## 请用'xfun::attr2()'。
## 见help("Deprecated")
```

pointx	pointy	treex	treey	Species	LAI
17.310644	26.43245	16.31137	25.048535	LS	10.05055
15.306900	33.43215	14.21762	29.750000	LX	0.00000
27.092897	26.53395	26.34198	29.750000	LX	0.00000
7.255326	34.95889	10.18809	36.037507	ZD	15.39914
23.741971	21.80406	23.31089	24.500000	LX	0.00000
24.350829	11.85681	22.67717	12.869234	HS	15.18164
37.496105	35.81206	37.09486	34.353282	ZD	12.69569
19.812821	40.27814	20.27980	40.250000	LX	0.00000
26.862344	26.96387	26.34198	29.750000	LX	0.00000
11.810482	16.10895	15.33661	16.214938	SMQ	17.00122
29.999859	24.53224	27.86636	22.076860	SMQ	25.00448
40.286621	42.14020	38.46633	40.250000	LX	0.00000
16.214154	18.94768	18.14606	19.266050	HS	35.88500
20.939516	43.16631	20.27980	40.250000	LX	0.00000
35.502043	32.81097	37.09486	34.353282	ZD	12.69569
31.760868	40.57814	32.40416	40.250000	LX	0.00000
13.184486	12.21629	10.92124	11.592341	HS	10.21953
19.300994	30.17563	20.27980	29.750000	LX	0.00000
19.379005	44.58257	17.24871	45.500000	LX	0.00000
32.611621	10.21155	31.41985	6.278545	ZD	20.20589

2.12 Local.single.point.Voronoi.LAI(minx, maxx, miny, maxy, boundary, a, b, r, Lr)

2.12.1 Introduction to functions:

Calculate the local canopy structure parameters related to leaf area at any single point in the forest land of a single layer within a single-layer forest or a multi-layer forest based on the Voronoi diagram method.

2.12.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the plot boundary buffer zone

a — coordinates of the position for which the local canopy structure parameters need to be simulated

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points. Sample points will be added at positions where there are no trees in the stand to prevent excessively large Voronoi polygons centered on trees.

Lr — radius of the circle used for extracting local canopy structure parameters

2.12.3 Example:

```
set.seed(100)
a=matrix(runif(2,5,45),1,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
a
```

```
##          x       y
## 1 17.31064 15.3069
```

```
b=Broadleaf.Korean.pine.LAI::b
b=subset(b,b$H>20 & b$H<30)
b=b[,-4]
head(b)
```

```
##           x          y      DBH Species
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
## 7 18.299115 36.464101 31.79671      HS
## 8 25.667076  4.623330 31.56699      HS
```

```
result=Broadleaf.Korean.pine.LAI::Local.single.point.Voronoi.LAI(minx=0,maxx=50,miny=0,maxy=50,boundary=5,a=a,b=b,r=3.5,Lr=1.5)
formattable::formattable(result)
```

```
## Warning in attr(x, "align"): xfun::attr()不再有用。
## 请用'xfun::attr2()'。
## 见help("Deprecated")
```

x	y	LAI	Local_min_LAI	Local_max_LAI	Local_mean_LAI	Local_sd_LAI	Gap_percent	Canopy_percent	N_L_Percent	B_L_
17.31064	15.3069	17.00122	17.00122	35.885	17.20648	1.961598	0	1	0.02266904	0

2.14 Semivariogram.Voronoi.LAI.Single(minx, maxx, miny, maxy, boundary, b, r, seq)

2.14.1 Introduction to functions:

Simulate the semivariogram of leaf area index for a single layer in a single-layer forest or a multi-layer forest based on the Voronoi diagram method.

2.14.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the plot boundary buffer zone

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points. Sample points will be added at positions where there are no trees in the stand to prevent excessively large Voronoi polygons centered on trees.

seq — spatial resolution for simulating the semivariogram

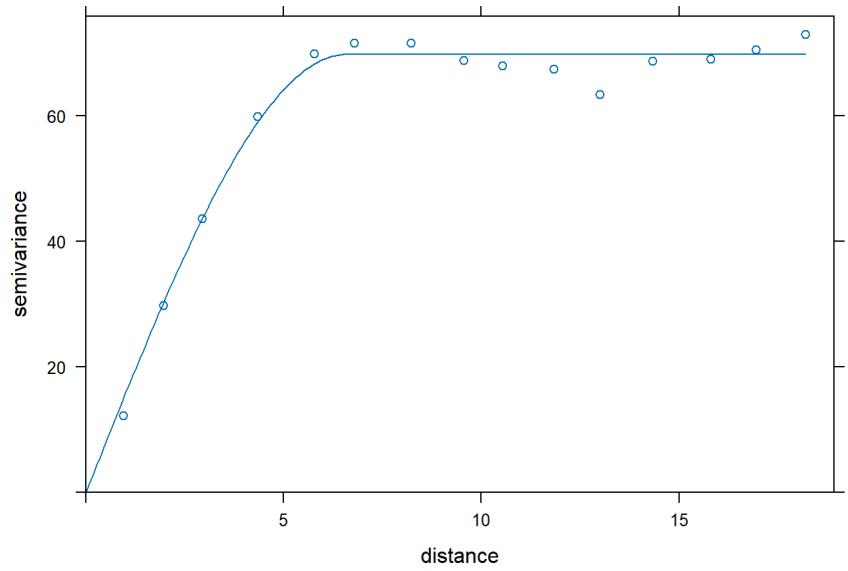
2.14.3 Example:

```
b=Broadleaf.Korean.pine.LAI::b
b=subset(b,b$H>20 & b$H<30)
b=b[,-4]
head(b)
```

```
##           x          y      DBH Species
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
## 7 18.299115 36.464101 31.79671      HS
## 8 25.667076  4.623330 31.56699      HS
```

```
Broadleaf.Korean.pine.LAI::Semivariogram.Voronoi.LAI.Single(minx=0,maxx=50,miny=0,maxy=50,boundary=5,b=b,r=3.5,seq=20)
```

```
##   model    psill    range
## 1   Nug  0.00000 0.000000
## 2   Sph 69.79591 6.601658
```




```
## [1] "Coefficient_of_Determination= 0.981974004649492"
```

2.15 Plot.Voronoi.LAI.Sum(minx, maxx, miny, maxy, boundary, b, strata, r)

2.15.1 Introduction to functions:

Draw the stand leaf area index map of multi-layer forests based on the stratified Voronoi diagram method.

2.15.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the plot boundary buffer zone

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

strata — division height between different forest layers

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points in each layer of the stand. Sample points will be added at positions where there are no trees in each layer to prevent excessively large Voronoi polygons centered on trees.

2.15.3 Example:

```
b=Broadleaf.Korean.pine.LAI::b
head(b)
```

```
##           x          y      DBH  H Species
## 1 33.428848 18.981981 65.58075 35      HS
## 2  6.434608 42.039176 66.18077 35      HS
## 3 18.146064 19.266050 52.26441 25      HS
## 4 27.592828 13.896808 32.36649 25      HS
## 5  6.108164 25.639671 35.55580 25      HS
## 6 39.511178  5.185569 53.03717 25      HS
```

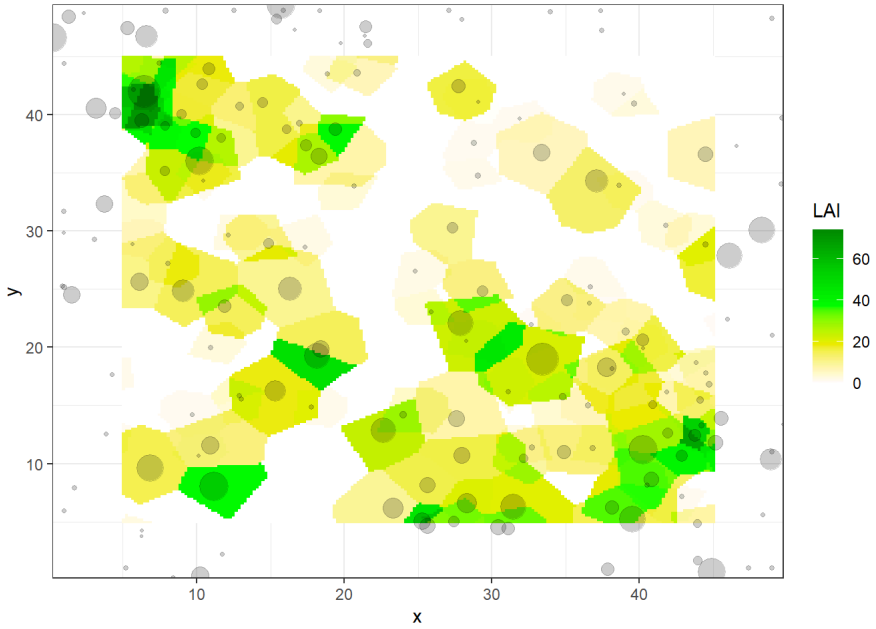
```
p=Broadleaf.Korean.pine.LAI::Plot.Voronoi.LAI.Sum(minx=0,maxx=50,miny=0,maxy=50,boundary=5,b=b,strata=c(10,16,30),r=c(2,2.5,3.5,4))
p1=p+geom_vline(xintercept = c(5,45),linetype=2)+geom_hline(yintercept =c(5,45),linetype=2)
p1=p+scale_x_continuous(expand= c(0, 5))+scale_y_continuous(expand= c(0, 5))
```

```
## Scale for x is already present.
## Adding another scale for x, which will replace the existing scale.
## Scale for y is already present.
## Adding another scale for y, which will replace the existing scale.
```

```
p2=p1+geom_point(data=b,aes(x=x,y=y),size=b$DBH/8,col="grey4",alpha=0.2)+scale_x_continuous(expand= c(0, 0))+scale_y_continuous(expand= c(0, 0))
```

```
## Scale for x is already present.
## Adding another scale for x, which will replace the existing scale.
## Scale for y is already present.
## Adding another scale for y, which will replace the existing scale.
```

```
p2
```



2.16 Single.point.Voronoi.LAI.sum(minx, maxx, miny, maxy, boundary, a, b, strata, r)

2.16.1 Introduction to functions:

Calculate the leaf area index at any single point in a multi-layer forest based on the stratified Voronoi diagram method.

2.16.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the plot boundary buffer zone

a — coordinates of the point for which the leaf area index needs to be calculated

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

strata — division height between different forest layers

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points in each layer of the stand. Sample points will be added at positions where there are no trees in each layer to prevent excessively large Voronoi polygons centered on trees.

2.16.3 Example:

```
set.seed(100)
a=matrix(runif(2,5,45),1,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
a
```

```
##          x       y
## 1 17.31064 15.3069
```

```
b=Broadleaf.Korean.pine.LAI::b
head(b)
```

```
##           x         y      DBH  H Species
## 1 33.428848 18.981981 65.58075 35      HS
## 2  6.434608 42.039176 66.18077 35      HS
## 3 18.146064 19.266050 52.26441 25      HS
## 4 27.592828 13.896808 32.36649 25      HS
## 5  6.108164 25.639671 35.55580 25      HS
## 6 39.511178  5.185569 53.03717 25      HS
```

```
result=Broadleaf.Korean.pine.LAI::Single.point.Voronoi.LAI.sum(minx=0,maxx=50,miny=0,maxy=50,boundary=5,a=a,b=b,strata=c(10,16,30),r=c(2,2.5,3.5,4))
result
```

```
##             x       y Species      LAI Species LAI Species      LAI Species LAI
## 1291 17.31064 15.3069      HS 1.776275      LX   0     SMQ 17.00122      LX   0
##        SumLAI Strata_cont
## 1291 18.77749    1.124323
```

2.17 mult.point.Voronoi.LAI.sum(minx, maxx, miny, maxy, boundary, a, b, strata, r)

2.17.1 Introduction to functions:

Calculate the leaf area index at multiple arbitrary points in a multi-layer forest based on the stratified Voronoi diagram method.

2.17.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the plot boundary buffer zone

a — coordinates of the points for which the leaf area index needs to be calculated

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

strata — division height between different forest layers

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points in each layer of the stand. Sample points will be added at positions where there are no trees in each layer to prevent excessively large Voronoi polygons centered on trees.

2.17.3 Example:

```
set.seed(100)
a=matrix(runif(40,5,45),20,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
a
```

```
##            x        y
## 1  17.310644 26.43245
## 2  15.306900 33.43215
## 3  27.092897 26.53395
## 4   7.255326 34.95889
## 5  23.741971 21.80406
## 6  24.350829 11.85681
## 7  37.496105 35.81206
## 8  19.812821 40.27814
## 9  26.862344 26.96387
## 10 11.810482 16.10895
## 11 29.999859 24.53224
## 12 40.286621 42.14020
## 13 16.214154 18.94768
## 14 20.939516 43.16631
## 15 35.502043 32.81097
## 16 31.760868 40.57814
## 17 13.184486 12.21629
## 18 19.300994 30.17563
## 19 19.379005 44.58257
## 20 32.611621 10.21155
```

```
b=Broadleaf.Korean.pine.LAI::b
head(b)
```

```
##           x          y      DBH  H Species
## 1 33.428848 18.981981 65.58075 35      HS
## 2  6.434608 42.039176 66.18077 35      HS
## 3 18.146064 19.266050 52.26441 25      HS
## 4 27.592828 13.896808 32.36649 25      HS
## 5  6.108164 25.639671 35.55580 25      HS
## 6 39.511178  5.185569 53.03717 25      HS
```

```
result=Broadleaf.Korean.pine.LAI::mult.point.Voronoi.LAI.sum(minx=0,maxx=50,miny=0,maxy=50,boundary=5,a=a,b=b,strata=c(10,16,30),r=c(2,2.5,3.5,4))
head(result)
```

```
##           x        y Species LAI Species      LAI Species      LAI Species LAI
## 1 17.310644 26.43245       LX   0      LX 0.000000      LS 10.05055      LX   0
## 2 15.306900 33.43215       LX   0      LX 0.000000      LX  0.00000      LX   0
## 3 27.092897 26.53395       LX   0      LX 0.000000      LX  0.00000      LX   0
## 4  7.255326 34.95889       LX   0     SMQ 7.813829      ZD 15.39914      LX   0
## 5 23.741971 21.80406       LX   0      LX 0.000000      LX  0.00000      LX   0
## 6 24.350829 11.85681       LX   0      LX 0.000000      HS 15.18164      LX   0
##     SumLAI Strata_cont
## 1 10.05055    1.200000
## 2  0.00000         NaN
## 3  0.00000         NaN
## 4 23.21297    1.065354
## 5  0.00000         NaN
## 6 15.18164    1.200000
```

2.18 Local.single.point.Voronoi.LAI.sum(minx, maxx, miny, maxy, boundary, a, b, strata, r, Lr)

2.18.1 Introduction to functions:

Calculate the local canopy structure characteristics related to leaf area index at any single point in a multi-layer forest based on the stratified Voronoi diagram method.

2.18.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the plot boundary buffer zone

a — coordinates of the point for which the local canopy structure parameters need to be simulated

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

strata — division height between different forest layers

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points in each layer of the stand. Sample points will be added at positions where there are no trees in each layer to prevent excessively large Voronoi polygons centered on trees.

Lr — radius of the circle for simulating local canopy structure parameters

2.18.3 Example:

```
set.seed(100)
a=matrix(runif(2,5,45),1,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
a
```

```
##          x       y
## 1 17.31064 15.3069
```

```
b=Broadleaf.Korean.pine.LAI::b
head(b)
```

```
##           x          y      DBH  H Species
## 1 33.428848 18.981981 65.58075 35      HS
## 2  6.434608 42.039176 66.18077 35      HS
## 3 18.146064 19.266050 52.26441 25      HS
## 4 27.592828 13.896808 32.36649 25      HS
## 5  6.108164 25.639671 35.55580 25      HS
## 6 39.511178  5.185569 53.03717 25      HS
```

```
result=Broadleaf.Korean.pine.LAI::Local.single.point.Voronoi.LAI.sum(minx=0,maxx=50,miny=0,maxy=50,boundary=5,a=a,b=b,strata=c(10,16,30),r=c(2,2.5,3.5,4),Lr=1.5)
formattable::formattable(result)
```

```
## Warning in attr(x, "align"): xfun::attr()不再有用。
## 请用'xfun::attr2()'。
## 见help("Deprecated")
```

x	y	LAI	Local_min_LAI	Local_max_LAI	Local_mean_LAI	Local_sd_LAI	Gap_percent	Canopy_percent	N_L_Percent	B_L_
17.31064	15.3069	18.77749	17.00122	35.885	18.58303	1.961076	0	1	0.09510175	0.9

2.19 Local.mult.point.Voronoi.LAI.sum(minx, maxx, miny, maxy, boundary, a, b, strata, r, Lr)

2.19.1 Introduction to functions:

Calculate the local canopy structure characteristics related to leaf area index at multiple arbitrary points in a multi-layer forest based on the stratified Voronoi diagram method.

2.19.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the plot boundary buffer zone

a — coordinates of the points for which the local canopy structure parameters need to be simulated

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

strata — division height between different forest layers

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points in each layer of the stand. Sample points will be added at positions where there are no trees in each layer to prevent excessively large Voronoi polygons centered on trees.

Lr — radius of the circle for simulating local canopy structure parameters

2.19.3 Example:

```
set.seed(100)
a=matrix(runif(40,5,45),20,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
a
```

```
##            x        y
## 1  17.310644 26.43245
## 2  15.306900 33.43215
## 3  27.092897 26.53395
## 4   7.255326 34.95889
## 5  23.741971 21.80406
## 6  24.350829 11.85681
## 7  37.496105 35.81206
## 8  19.812821 40.27814
## 9  26.862344 26.96387
## 10 11.810482 16.10895
## 11 29.999859 24.53224
## 12 40.286621 42.14020
## 13 16.214154 18.94768
## 14 20.939516 43.16631
## 15 35.502043 32.81097
## 16 31.760868 40.57814
## 17 13.184486 12.21629
## 18 19.300994 30.17563
## 19 19.379005 44.58257
## 20 32.611621 10.21155
```

```
b=Broadleaf.Korean.pine.LAI::b
head(b)
```

```
##           x          y      DBH  H Species
## 1 33.428848 18.981981 65.58075 35      HS
## 2  6.434608 42.039176 66.18077 35      HS
## 3 18.146064 19.266050 52.26441 25      HS
## 4 27.592828 13.896808 32.36649 25      HS
## 5  6.108164 25.639671 35.55580 25      HS
## 6 39.511178  5.185569 53.03717 25      HS
```

```
result=Broadleaf.Korean.pine.LAI::Local.mult.point.Voronoi.LAI.sum(minx=0,maxx=50,miny=0,maxy=50,boundary=5,a=a,b=b,strata=c(10,16,30),r=c(2,2.5,3.5,4),Lr=1.5)
formattable::formattable(result)
```

```
## Warning in attr(x, "align"): xfun::attr()不再有用。
## 请用'xfun::attr2()'。
## 见help("Deprecated")
```

x	y	LAI	Local_min_LAI	Local_max_LAI	Local_mean_LAI	Local_sd_LAI	Gap_percent	Canopy_percent	N_L_Percent	B
17.310644	26.43245	10.050552	2.690695	20.828866	10.7147251	2.3322292	0.000000000	1.0000000	9.244186e-01	
15.306900	33.43215	0.000000	0.000000	15.399139	3.0199286	3.7169435	0.583333333	0.4166667	9.260989e-01	
27.092897	26.53395	0.000000	0.000000	34.043668	9.3393815	11.3374783	0.387681159	0.6123188	0.000000e+00	
7.255326	34.95889	23.212968	5.682379	23.212968	20.4785193	4.7019453	0.000000000	1.0000000	6.434319e-02	
23.741971	21.80406	0.000000	0.000000	27.658909	1.0684987	3.7782547	0.768115942	0.2318841	0.000000e+00	
24.350829	11.85681	15.181635	8.612138	19.622435	16.8431834	2.5533648	0.000000000	1.0000000	7.509366e-01	
37.496105	35.81206	12.695686	12.695686	13.553238	12.9473590	0.3912004	0.000000000	1.0000000	1.943816e-02	
19.812821	40.27814	13.954960	3.951567	13.954960	12.6883215	3.2951356	0.000000000	1.0000000	0.000000e+00	
26.862344	26.96387	0.000000	0.000000	34.043668	6.5623799	7.6423820	0.362318841	0.6376812	0.000000e+00	
11.810482	16.10895	20.190508	0.000000	20.190508	12.9948255	7.6361437	0.007246377	0.9927536	3.363830e-01	
29.999859	24.53224	34.043668	9.039184	34.697197	32.1435207	6.6424587	0.000000000	1.0000000	7.366519e-05	
40.286621	42.14020	1.892003	0.000000	2.680474	1.4276083	1.1143551	0.358695652	0.6413043	4.897832e-01	
16.214154	18.94768	35.885000	0.000000	35.885000	18.2607897	16.9411836	0.431159420	0.5688406	9.021751e-01	
20.939516	43.16631	6.874069	0.000000	6.874069	5.0856611	1.9804229	0.072463768	0.9275362	0.000000e+00	
35.502043	32.81097	12.695686	0.000000	12.695686	11.4537169	3.7784775	0.097826087	0.9021739	0.000000e+00	
31.760868	40.57814	1.383401	0.000000	1.383401	1.2903732	0.2923163	0.010869565	0.9891304	2.890046e-02	
13.184486	12.21629	10.219530	0.000000	19.087753	9.7674311	4.3535498	0.141304348	0.8586957	8.963959e-01	
19.300994	30.17563	0.000000	0.000000	2.690695	0.8871494	1.2672144	0.670289855	0.3297101	0.000000e+00	
19.379005	44.58257	6.874069	3.951567	13.363972	7.7183572	2.6493807	0.000000000	1.0000000	0.000000e+00	
32.611621	10.21155	30.735542	10.529653	37.667190	23.9694583	7.9062509	0.000000000	1.0000000	6.747978e-02	

2.20 Semivariogram.Voronoi.LAI(minx, maxx, miny, maxy, boundary, b, strata, r, seq)

2.20.1 Introduction to functions:

Simulate the semivariogram of leaf area index in multi-layer forests based on the stratified Voronoi diagram method.

2.20.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the buffer zone

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

strata — division height between different forest layers

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points. Sample points will be added at positions where there are no trees in the stand to prevent excessively large Voronoi polygons centered on trees.

seq — spatial resolution for simulating the semivariogram

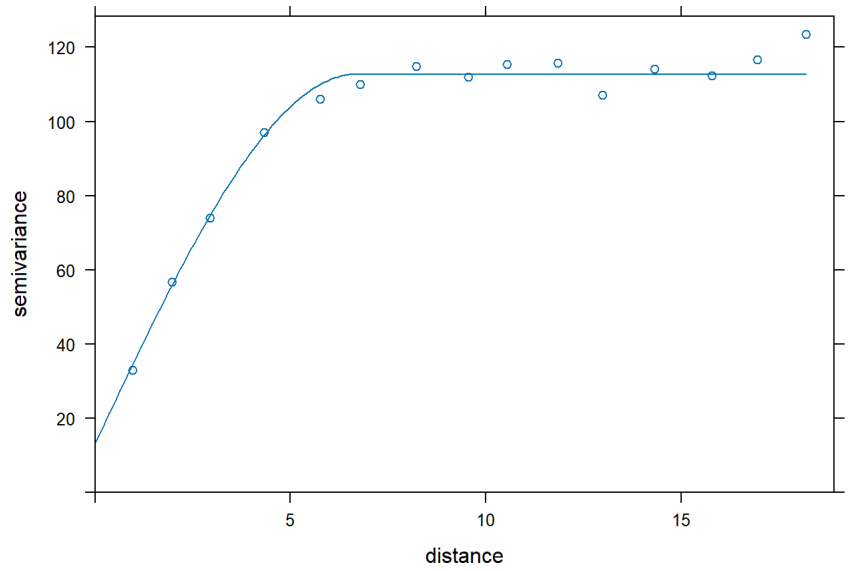
2.20.3 Example:

```
b=Broadleaf.Korean.pine.LAI::b
head(b)
```

```
##           x          y      DBH  H Species
## 1 33.428848 18.981981 65.58075 35      HS
## 2  6.434608 42.039176 66.18077 35      HS
## 3 18.146064 19.266050 52.26441 25      HS
## 4 27.592828 13.896808 32.36649 25      HS
## 5  6.108164 25.639671 35.55580 25      HS
## 6 39.511178  5.185569 53.03717 25      HS
```

```
Broadleaf.Korean.pine.LAI::Semivariogram.Voronoi.LAI(minx=0,maxx=50,miny=0,maxy=50,boundary =5,b=b,strata=c(10,16,30),r=c(2,2.5,3.5,4),seq = 20)
```

```
##   model    psill    range
## 1   Nug 13.27126 0.000000
## 2   Sph 99.49735 6.691065
```




```
## [1] "Coefficient_of_Determination= 0.977115571818784"
```

2.21 plot.Local.single.point.Voronoi.LAI(minx, maxx, miny, maxy, a, b, r, Lr)

2.21.1 Introduction to functions:

Calculate the local canopy structure parameters related to leaf area at any single point in the forest land of a single layer within a single-layer forest or a multi-layer forest based on the Voronoi diagram method, and plot for verification.

2.21.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

a — coordinates of the position for which the local canopy structure parameters need to be simulated

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points. Sample points will be added at positions where there are no trees in the stand to prevent excessively large Voronoi polygons centered on trees.

Lr — radius of the circle used for extracting local canopy structure parameters

2.21.3 Example:

```
set.seed(100)
a=matrix(runif(2,5,45),1,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
a
```

```
##          x       y
## 1 17.31064 15.3069
```

```
b=Broadleaf.Korean.pine.LAI::b
b=subset(b,b$H>20 & b$H<30)
b=b[,-4]
head(b)
```

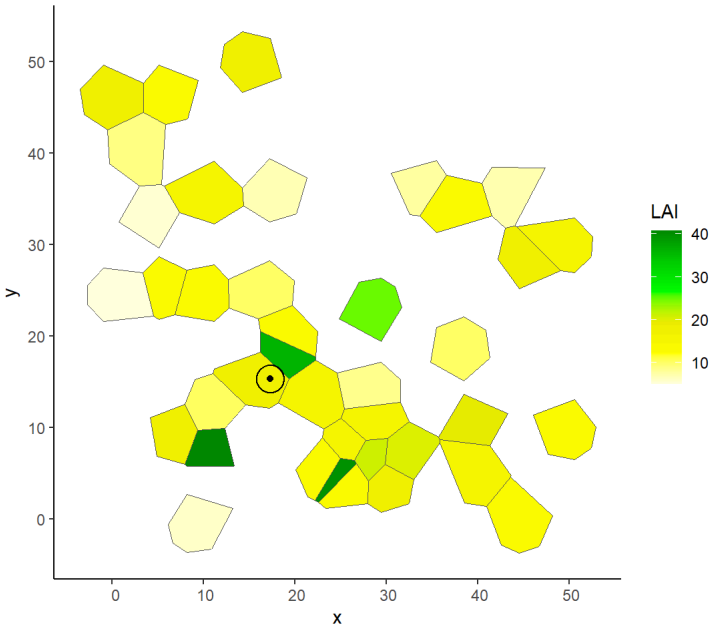
```
##           x          y      DBH Species
## 3 18.146064 19.266050 52.26441      HS
## 4 27.592828 13.896808 32.36649      HS
## 5  6.108164 25.639671 35.55580      HS
## 6 39.511178  5.185569 53.03717      HS
## 7 18.299115 36.464101 31.79671      HS
## 8 25.667076  4.623330 31.56699      HS
```

```
Broadleaf.Korean.pine.LAI::plot.Local.single.point.Voronoi.LAI(minx=0,maxx=50,miny=0,maxy=50,a=a,b=b,r=3.5,Lr=1.5)
```

```
##          x       y      LAI Local_min_LAI Local_max_LAI Local_mean_LAI
## 1 17.31064 15.3069 17.00122       17.00122        35.885        17.20648
##   Local_sd_LAI Gap_percent Canopy_percent N_L_Percent B_L_Percent
## 1     1.961598           0              1  0.02266904    0.977331
```

```
## rgeos version: 0.6-4, (SVN revision (unknown))
##  GEOS runtime version: 3.12.1-CAPI-1.18.1
##  Please note that rgeos will be retired during October 2023,
## plan transition to sf or terra functions using GEOS at your earliest convenience.
## See https://r-spatial.org/r/2023/05/15/evolution4.html for details.
##  GEOS using OverlayNG
##  Linking to sp version: 2.1-4
##  Polygon checking: TRUE
```

```
## Linking to GEOS 3.13.0, GDAL 3.10.1, PROJ 9.5.1; sf_use_s2() is TRUE
```



2.22 plot.Local.single.point.Voronoi.LAI.sum(minx, maxx, miny, maxy, a, b, strata, r, Lr)

2.22.1 Introduction to functions:

Calculate the local canopy structure characteristics related to leaf area index at any single point in a multi-layer forest based on the stratified Voronoi diagram method, and plot the result.

2.22.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

a — coordinates of the point for which the local canopy structure parameters need to be simulated

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

strata — division height between different forest layers

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points in each layer of the stand. Sample points will be added at positions where there are no trees in each layer to prevent excessively large Voronoi polygons centered on trees.

Lr — radius of the circle for simulating local canopy structure parameters

2.22.3 Example:

```
set.seed(100)
a=matrix(runif(2,5,45),1,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
a
```

```
##          x       y
## 1 17.31064 15.3069
```

```
b=Broadleaf.Korean.pine.LAI::b
head(b)
```

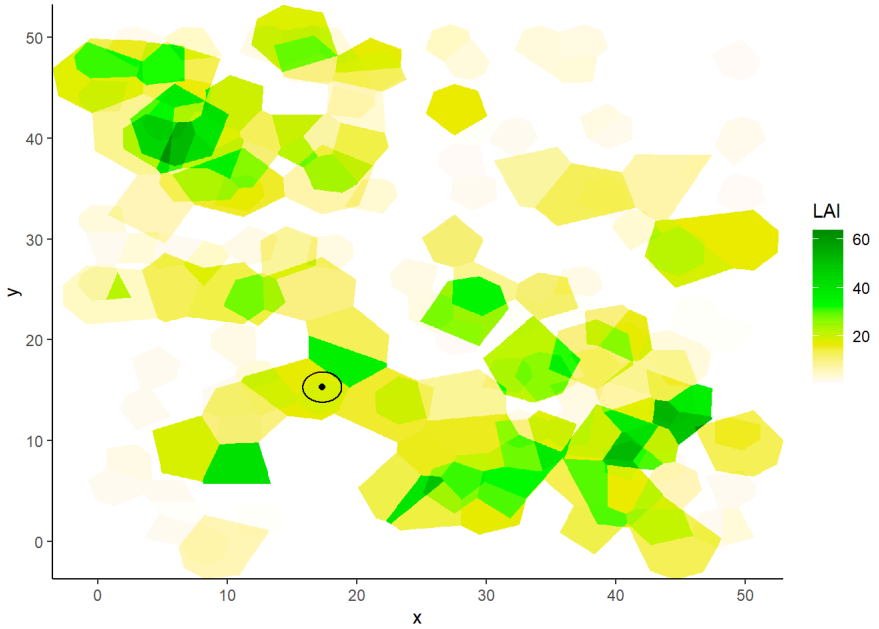
```
##           x         y      DBH  H Species
## 1 33.428848 18.981981 65.58075 35      HS
## 2  6.434608 42.039176 66.18077 35      HS
## 3 18.146064 19.266050 52.26441 25      HS
## 4 27.592828 13.896808 32.36649 25      HS
## 5  6.108164 25.639671 35.55580 25      HS
## 6 39.511178  5.185569 53.03717 25      HS
```

```
gc()
```

```
##           used  (Mb) gc trigger  (Mb) max used  (Mb)
## Ncells 2048351 109.4    3655797 195.3  2919654 156.0
## Vcells 3707075  28.3   10168975  77.6 10168975  77.6
```

```
Broadleaf.Korean.pine.LAI::plot.Local.single.point.Voronoi.LAI.sum(minx=0,maxx=50,miny=0,maxy=50,a=a,b=b,strata=c(10,16,30),r=c(2,2.5,3.5,4),Lr=1.5)
```

```
##          x       y      LAI Local_min_LAI Local_max_LAI Local_mean_LAI
## 1 17.31064 15.3069 18.77749      17.00122        35.885       18.58373
##   Local_sd_LAI Gap_percent Canopy_percent N_L_Percent B_L_Percent Strata_cont
## 1     1.957542           0              1   0.0950999   0.9049001    1.140711
```



2.23 Voronoi.LAI.sum.ISAA(minx, maxx, miny, maxy, boundary, b, seq, strata, r, indis, lag)

2.23.1 Introduction to functions:

Perform incremental spatial autocorrelation analysis of leaf area index in multi-layer forests based on the stratified Voronoi diagram method.

2.23.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the buffer zone

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

seq — spatial resolution

strata — division height between different forest layers

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points in each layer of the stand. Sample points will be added at positions where there are no trees in each layer to prevent excessively large Voronoi polygons centered on trees.

indis — initial distance

lag — lag distance increment

2.23.3 Example:

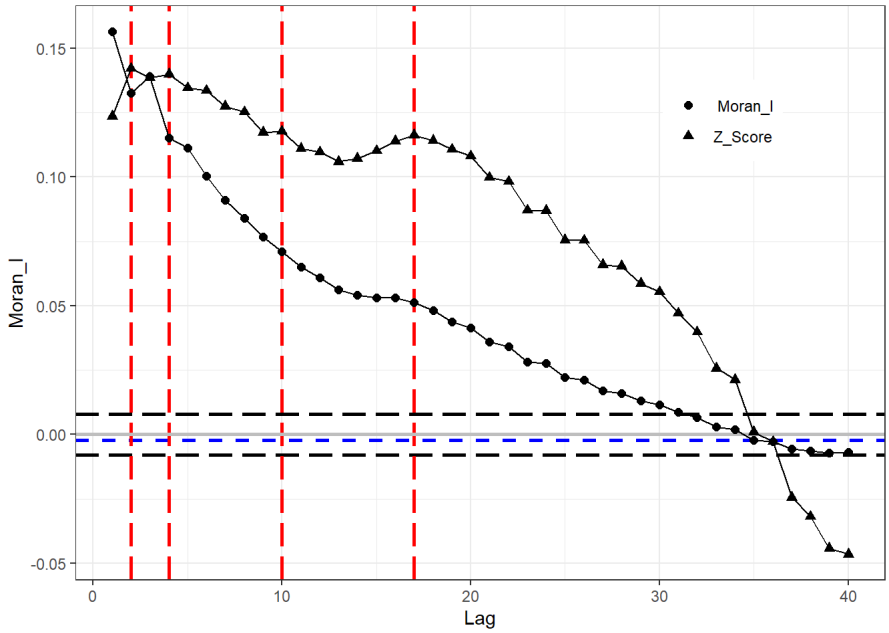
```
b=Broadleaf.Korean.pine.LAI::b
head(b)
```

```
##           x         y      DBH  H Species
## 1 33.428848 18.981981 65.58075 35      HS
## 2  6.434608 42.039176 66.18077 35      HS
## 3 18.146064 19.266050 52.26441 25      HS
## 4 27.592828 13.896808 32.36649 25      HS
## 5  6.108164 25.639671 35.55580 25      HS
## 6 39.511178  5.185569 53.03717 25      HS
```

```
Broadleaf.Korean.pine.LAI::Voronoi.LAI.sum.ISAA(minx=0, maxx=50, miny=0, maxy=50, boundary=5, b=b, seq=20, strata=c(10,16,30),r=c(2,2.5,3.5,4), indis=1, lag=1)
```

```
##
## 载入程序包：'ape'
```

```
## The following objects are masked from 'package:raster':
##
##     rotate, zoom
```



2.24 plot.M.COMMUNITIES.Voronoi.LAI.sum(minx, maxx, miny, maxy, a, b, strata, r, Min_com_edge)

2.24.1 Introduction to functions:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points in each layer of the stand. Sample points will be added at positions where there are no trees in each layer to prevent excessively large Voronoi polygons centered on trees.

Min_com_edge — the range of outward extension of the local community

2.24.3 Example:

```
b=Broadleaf.Korean.pine.LAI::b
head(b)
```

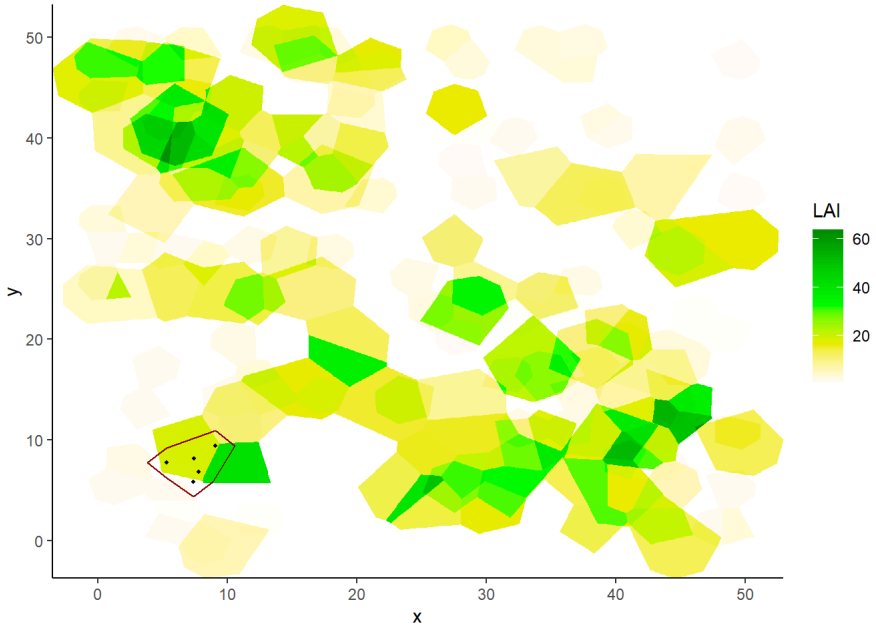
```
##           x         y      DBH  H Species
## 1 33.428848 18.981981 65.58075 35      HS
## 2  6.434608 42.039176 66.18077 35      HS
## 3 18.146064 19.266050 52.26441 25      HS
## 4 27.592828 13.896808 32.36649 25      HS
## 5  6.108164 25.639671 35.55580 25      HS
## 6 39.511178  5.185569 53.03717 25      HS
```

```
a=matrix(runif(10,5,10),5,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
a
```

```
##          x        y
## 1 7.761612 6.851603
## 2 5.281916 7.732793
## 3 7.342746 5.851310
## 4 7.418854 8.124982
## 5 9.062013 9.410828
```

```
Broadleaf.Korean.pine.LAI::plot.M.COMMUNITIES.Voronoi.LAI.sum(minx=0,maxx=50,miny=0,maxy=50,a=a,b=b,strata=c(10,16,30),r=c(2,2.5,3.5,4),Min_com_edge=1.5)
```

```
##          x        y Local_min_LAI Local_max_LAI Local_mean_LAI Local_sd_LAI
## 1 7.373428 7.594303             0       41.71074        18.90103      12.50539
##   Gap_percent Canopy_percent N_L_Percent B_L_Percent Strata_cont
## 1   0.1428571       0.8571429           1           0     1.194606
```



2.25 M.COMMUNITIES.Voronoi.LAI.sum(minx, maxx, miny, maxy, a, b, strata, r, Min_com_edge)

2.25.1 Introduction to functions:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points in each layer of the stand. Sample points will be added at positions where there are no trees in each layer to prevent excessively large Voronoi polygons centered on trees.

Min_com_edge — the range of outward extension of the local community

2.25.3 Example:

```
b=Broadleaf.Korean.pine.LAI::b
head(b)
```

```
##           x          y      DBH  H Species
## 1 33.428848 18.981981 65.58075 35      HS
## 2  6.434608 42.039176 66.18077 35      HS
## 3 18.146064 19.266050 52.26441 25      HS
## 4 27.592828 13.896808 32.36649 25      HS
## 5  6.108164 25.639671 35.55580 25      HS
## 6 39.511178  5.185569 53.03717 25      HS
```

```
a=matrix(runif(30,5,10),5,2)
colnames(a)=c("x","y")
a=as.data.frame(a)
Broadleaf.Korean.pine.LAI::M.COMMUNITIES.Voronoi.LAI.sum(minx=0,maxx=50,miny=0,maxy=50,a=a,b=b,strata=c(10,16,30),r=c(2,2.5,3.5,4),Min_com_edge=1.5)
```

```
##          x        y Local_min_LAI Local_max_LAI Local_mean_LAI Local_sd_LAI
## 1 7.315027 7.653905             0      40.79078       20.46314     10.53655
##   Gap_percent Canopy_percent N_L_Percent B_L_Percent Strata_cont
## 1  0.07142857      0.9285714           1           0    1.198137
```

2.26 Voronoi.pointcloud(minx, maxx, miny, maxy, boundary, b, seq, strata, r, S, theta, phi)

2.26.1 Introduction to functions:

Invert the three-dimensional spatial distribution of leaf area based on the stratified Voronoi diagram method and plot it as a point cloud.

2.26.2 Parameter meanings:

minx — minimum range of the plot's abscissa

maxx — maximum range of the plot's abscissa

miny — minimum range of the plot's ordinate

maxy — maximum range of the plot's ordinate

boundary — width of the buffer zone

b — information on the coordinates, tree species, and DBH (diameter at breast height) of the trees in the plot

seq — spatial resolution for plotting the point cloud

strata — division height between different forest layers

r — radius of the circumscribed circle of the Voronoi diagram formed by adding sample points in each layer of the stand. Sample points will be added at positions where there are no trees in each layer to prevent excessively large Voronoi polygons centered on trees.

S — average crown shape ratio in the stand, the ratio of crown length to crown width

theta — horizontal flip angle for plotting

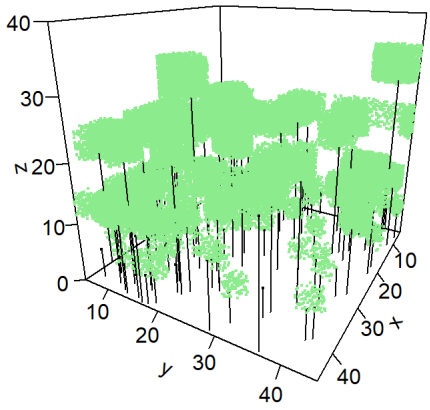
phi — vertical flip angle for plotting

2.26.3 Example:

```
b=Broadleaf.Korean.pine.LAI::b
head(b)
```

```
##           x          y      DBH  H Species
## 1 33.428848 18.981981 65.58075 35      HS
## 2  6.434608 42.039176 66.18077 35      HS
## 3 18.146064 19.266050 52.26441 25      HS
## 4 27.592828 13.896808 32.36649 25      HS
## 5  6.108164 25.639671 35.55580 25      HS
## 6 39.511178  5.185569 53.03717 25      HS
```

```
Broadleaf.Korean.pine.LAI::Voronoi.pointcloud(minx=0, maxx=50, miny=0, maxy=50, boundary=5, b=b, seq=100, strata=c(10,16,30),r=c(2,2.5,3.5,4), S=1.5, theta=120, phi=20)
```


40
30
z 20
10
0
10
20
y 30
40
10
20
30 x
40