Monte Carlo Simulation Tools for REDD+ Uncertainty Estimates

2024-12-19

Contents

Import data

```
workbook = "./data/art/GuyanaARTWorkbookMC-thru2022-April2024_values.xlsx"
CarbonStocks = readxl::read_excel(workbook, "CarbonStocks")
CarbonStocks = CarbonStocks |>
    mutate(across(where(is.numeric), ~round(.x, 1)))
CarbonStocks_MC = readxl::read_excel(workbook, "CarbonStocks (MC)")
CarbonStocks_MC = CarbonStocks_MC |>
    mutate(across(where(is.numeric), ~round(.x, 1)))

flextable(head(CarbonStocks[, 1:8])) |>
    fontsize(size = 8, part = "all")
```

...1	AG Tree (tC/ha)	BG Tree (tC/ha)	Saplings (tC/ha)	Standing Dead Wood (tC/ha)	Lying Dead Wood (tC/ha)	Sum Carbon pools w/o litter (t C/ha)	Litter (tC/ha)
mean of all plots (calculated)	205.8	48.3	3.7	2.6	8.6	269.0	3.3
std. dev	60.4	14.3	2.0	4.0	8.1	75.2	1.3
minimum	91.6	21.2	0.5	0.0	0.0		1.2
maximum	353.7	83.1	18.8	13.7	42.3		8.7
90% CI	9.2	2.2	0.3	0.6	1.2	11.5	0.2
CI as % of mean	0.0	0.0	0.1	0.2	0.1	0.0	

```
flextable(head(CarbonStocks_MC[, 1:8])) |>
    fontsize(size = 8, part = "all")
```

...1	AG Tree (tC/ha)	BG Tree (tC/ha)	Saplings (tC/ha)	Standing Dead Wood (tC/ha)	Lying Dead Wood (tC/ha)	Sum Carbon pools w/o litter (t C/ha)	Litter (tC/ha)
tC/ha	181.1	65.0	3.5	7.3	17.1		3.7
tCO2/ha	664.2	238.2	12.8	26.9	62.6		13.7

SimVoi Documentation:

SimVoi adds seventeen random number generator functions defined with the following syntax:

- `RandBeta(alpha,beta,,[MinValue],[MaxValue])`
- `RandBinomial(trials,probability_s)`
- `RandBiVarNormal(mean1,stdev1,mean2,stdev2,correl12)`
- `RandCumulative(value_cumulative_table)`
- `RandDiscrete(value_discrete_table)`
- `RandExponential(lambda)`
- `RandInteger(bottom,top)`
- `RandLogNormal(Mean,StDev)`
- `RandNormal(mean,standard_dev)`
- `RandPoisson(mean)`
- `RandSample(population)`
- `RandTriangular(minimum,most_likely,maximum)`
- `RandTriBeta(minimum,most_likely,maximum,[shape])`
- `RandTruncBiVarNormal(mean1,stdev1,mean2,stdev2,correl12, [min1],[max1],[min2],[max2])`
- `RandTruncLogNormal(Mean,StDev,[MinValue],[MaxValue])`
- `RandTruncNormal(Mean,StDev,[MinValue],[MaxValue])`
- `RandUniform(minimum,maximum)`

In the following, we attempt to match the SimVoi Excel formula of

`=[1]!randtruncnormal(CarbonStocks.B2,CarbonStocks.B3,0)`

function, as closely as random seeding allows. According to package documentation, the `RandTruncNormal()` function "*Returns a random value from a truncated normal probability density function. This function can model an uncertain quantity with a bell-shaped density function where extreme values in the tails of the distribution are not desired.*"

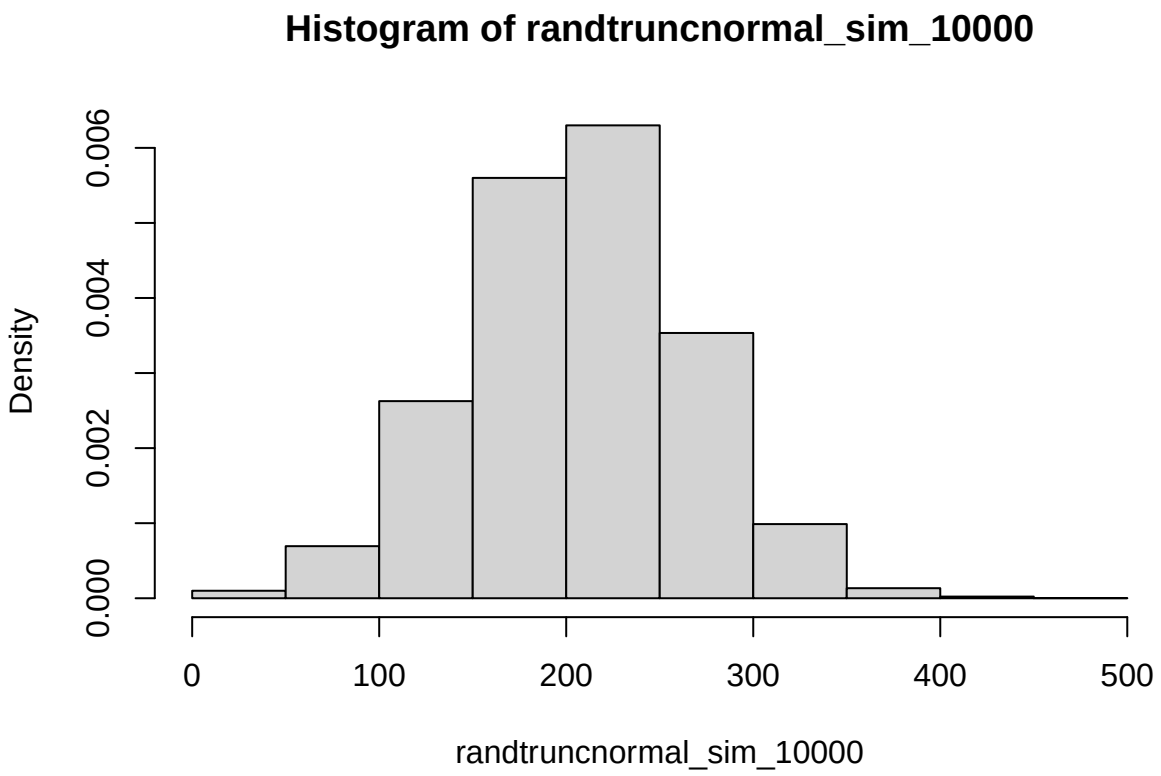
In terms of simulation parameters, *"RandTruncNormal(Mean,StDev,MinValue,MaxValue)) uses values of RandNormal until a value is found between MinValue and MaxValue or until it has made 10,000 attempts."* The above formula provides a minimum value of `0`, passing to the default number of simulations of 10,000.

Replication Method:

We utilize the replicate function to repeat a simulationfollowing a randomized normally truncated multiple times with `replicate(n=10000`, while determining the size of the sampled subset with `rnorm(n=100`. The first model explores sample size parameters only, replication parameters are tested below this in comparisons.

```
MEAN = CarbonStocks$`AG Tree (tC/ha)`[1]
SD = CarbonStocks$`AG Tree (tC/ha)`[2]

randtruncnormal_sim_10000 <- rnorm(n = 10000, mean = MEAN, sd = SD)
hist(randtruncnormal_sim_10000, freq = F)
```




```
AG_Tree_tC_ha = mean(randtruncnormal_sim_10000)
AG_Tree_tCO2_ha = AG_Tree_tC_ha * (44/12)
AG_Tree_tC_ha
```

```
[1] 206.5191
```

```
AG_Tree_tCO2_ha
```

```
[1] 757.2367
```

```
# curve(dnorm(x, mean=MEAN, sd=SD), from=0, to=450, add=T, col='red')
```

Compare simulations

```
# 10,000 simulations sampling 10 observations
randtruncnormal_sim_10000_10 = replicate(n = 10000, rnorm(n = 10, mean = MEAN, sd = SD))
hist(apply(X = randtruncnormal_sim_10000_10, MARGIN = 2, FUN = mean))
sd(apply(X = randtruncnormal_sim_10000_10, MARGIN = 2, FUN = mean))
```

```
[1] 19.21283
```

```
mean(apply(X = randtruncnormal_sim_10000_10, MARGIN = 2, FUN = mean))
```

```
[1] 206.1327
```

```
(mean(apply(X = randtruncnormal_sim_10000_10, MARGIN = 2, FUN = mean))) * (44/12)
```

```
[1] 755.8198
```

```
# 10,000 simulations sampling 100 observations
randtruncnormal_sim_10000_100 = replicate(n = 10000, rnorm(n = 100, mean = MEAN,
    sd = SD))
hist(apply(X = randtruncnormal_sim_10000_100, MARGIN = 2, FUN = mean))
sd(apply(X = randtruncnormal_sim_10000_100, MARGIN = 2, FUN = mean))
```

```
[1] 5.951618
```

```
mean(apply(X = randtruncnormal_sim_10000_100, MARGIN = 2, FUN = mean))
```

```
[1] 205.8461
```

```
(mean(apply(X = randtruncnormal_sim_10000_100, MARGIN = 2, FUN = mean))) * (44/12)
```

```
[1] 754.7689
```

```
# 10,000 simulations sampling 1,000 observations
randtruncnormal_sim_10000_1000 = replicate(n = 10000, rnorm(n = 1000, mean = MEAN,
    sd = SD))
hist(apply(X = randtruncnormal_sim_10000_1000, MARGIN = 2, FUN = mean))
sd(apply(X = randtruncnormal_sim_10000_1000, MARGIN = 2, FUN = mean))
```

```
[1] 1.915574
```

```
mean(apply(X = randtruncnormal_sim_10000_1000, MARGIN = 2, FUN = mean))
```

```
[1] 205.7926
```

```
(mean(apply(X = randtruncnormal_sim_10000_1000, MARGIN = 2, FUN = mean))) * (44/12)
```

```
[1] 754.5727
```

```
# 10,000 simulations sampling 10,000 observations
randtruncnormal_sim_10000_10000 = replicate(n = 10000, rnorm(n = 10000, mean = MEAN,
    sd = SD))
hist(apply(X = randtruncnormal_sim_10000_10000, MARGIN = 2, FUN = mean))
sd(apply(X = randtruncnormal_sim_10000_10000, MARGIN = 2, FUN = mean))
```

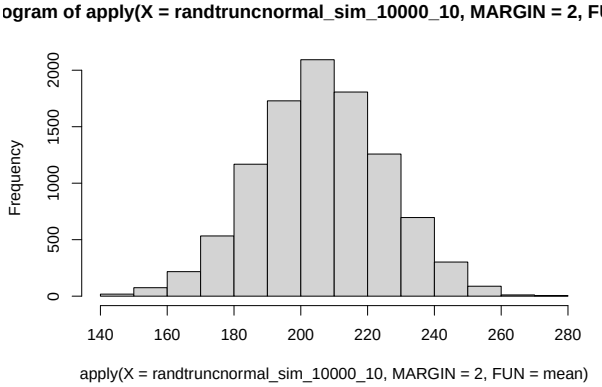
```
[1] 0.5994809
```

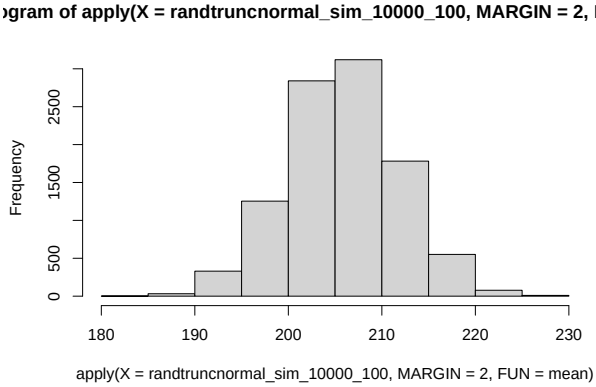
```
mean(apply(X = randtruncnormal_sim_10000_10000, MARGIN = 2, FUN = mean))
```

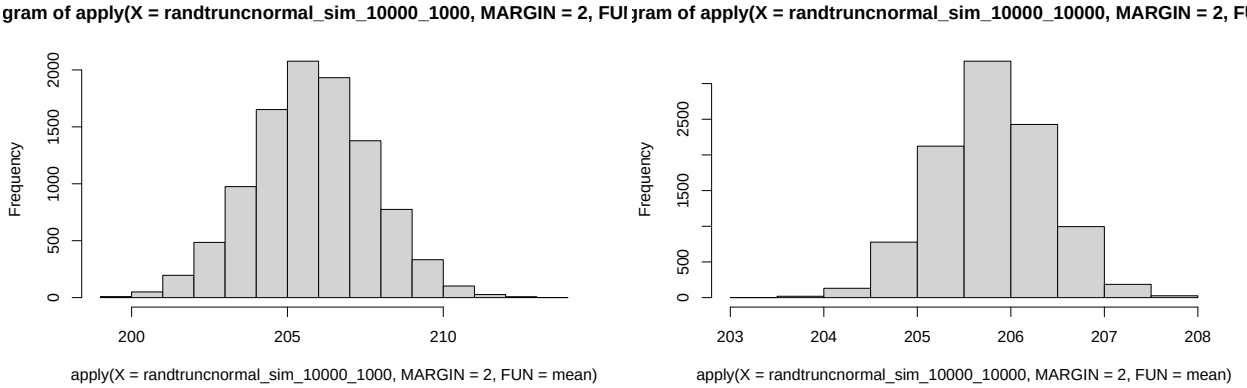
```
[1] 205.7971
```

```
(mean(apply(X = randtruncnormal_sim_10000_10000, MARGIN = 2, FUN = mean))) * (44/12)
```

```
[1] 754.5892
```








```
devtools::session_info()
```

```
- Session info -------------------------------------------------------------
 setting  value
 version  R version 4.4.2 (2024-10-31)
 os       Fedora Linux 40 (Workstation Edition)
 system   x86_64, linux-gnu
 ui       X11
 language (EN)
 collate  en_CA.UTF-8
 ctype    en_CA.UTF-8
 tz       America/Vancouver
 date     2025-02-04
 pandoc   3.1.3 @ /usr/libexec/rstudio/bin/pandoc/ (via rmarkdown)

- Packages -----------------------------------------------------------------
 package           * version    date (UTC) lib source
 abind               1.4-8      2024-09-12 [2] CRAN (R 4.4.1)
 allodb            * 0.0.1.9000 2024-12-19 [1] Github (ropensci/allodb@4207f86)
 animation         * 2.7        2021-10-07 [2] CRAN (R 4.4.0)
 askpass             1.2.1      2024-10-04 [2] CRAN (R 4.4.1)
 assertthat          0.2.1      2019-03-21 [2] CRAN (R 4.4.0)
 backports           1.5.0      2024-05-23 [2] CRAN (R 4.4.0)
 BIOMASS           * 2.1.11     2023-09-29 [2] CRAN (R 4.4.0)
 boot                1.3-31     2024-08-28 [2] CRAN (R 4.4.1)
 broom             * 1.0.7      2024-09-26 [2] CRAN (R 4.4.1)
 c2z               * 0.2.0      2023-08-10 [2] CRAN (R 4.4.0)
 cachem              1.1.0      2024-05-16 [2] CRAN (R 4.4.0)
 car                 3.1-3      2024-09-27 [2] CRAN (R 4.4.1)
 carData             3.0-5      2022-01-06 [2] CRAN (R 4.4.0)
 caret             * 7.0-1      2024-12-10 [2] CRAN (R 4.4.2)
 cellranger          1.1.0      2016-07-27 [2] CRAN (R 4.4.0)
 chromote            0.4.0      2025-01-25 [2] CRAN (R 4.4.2)
 class               7.3-23     2025-01-01 [2] CRAN (R 4.4.2)
 classInt            0.4-11     2025-01-08 [2] CRAN (R 4.4.2)
 cli                 3.6.3      2024-06-21 [2] CRAN (R 4.4.0)
 codetools           0.2-20     2024-03-31 [2] CRAN (R 4.4.0)
 colorspace          2.1-1      2024-07-26 [2] CRAN (R 4.4.1)
 CoprManager         0.5.7      2024-10-31 [4] local
 data.table          1.16.4     2024-12-06 [2] CRAN (R 4.4.2)
 dataMaid          * 1.4.1      2021-10-08 [2] CRAN (R 4.4.1)
 DBI                 1.2.3      2024-06-02 [2] CRAN (R 4.4.0)
```

```
DEoptimR            1.1-3-1    2024-11-23 [2] CRAN (R 4.4.2)
DescTools         * 0.99.59    2025-01-26 [2] CRAN (R 4.4.2)
devtools            2.4.5      2022-10-11 [2] CRAN (R 4.4.0)
dials             * 1.3.0      2024-07-30 [2] CRAN (R 4.4.1)
DiceDesign          1.10       2023-12-07 [2] CRAN (R 4.4.0)
digest              0.6.37     2024-08-19 [2] CRAN (R 4.4.1)
dplyr             * 1.1.4      2023-11-17 [2] CRAN (R 4.4.0)
e1071               1.7-16     2024-09-16 [2] CRAN (R 4.4.1)
easypackages        0.1.0      2016-12-05 [2] CRAN (R 4.4.0)
ellipsis            0.3.2      2021-04-29 [2] CRAN (R 4.4.0)
evaluate            1.0.3      2025-01-10 [2] CRAN (R 4.4.2)
Exact               3.3        2024-07-21 [2] CRAN (R 4.4.1)
expm                1.0-0      2024-08-19 [2] CRAN (R 4.4.1)
extrafont         * 0.19       2023-01-18 [2] CRAN (R 4.4.0)
extrafontdb         1.0        2012-06-11 [2] CRAN (R 4.4.0)
fastmap             1.2.0      2024-05-15 [2] CRAN (R 4.4.0)
flextable         * 0.9.7      2024-10-27 [2] CRAN (R 4.4.1)
fontBitstreamVera   0.1.1      2017-02-01 [2] CRAN (R 4.4.0)
fontLiberation      0.1.0      2016-10-15 [2] CRAN (R 4.4.0)
fontquiver          0.2.1      2017-02-01 [2] CRAN (R 4.4.0)
forcats           * 1.0.0      2023-01-29 [2] CRAN (R 4.4.0)
foreach             1.5.2      2022-02-02 [2] CRAN (R 4.4.0)
formatR           * 1.14       2023-01-17 [2] CRAN (R 4.4.0)
Formula             1.2-5      2023-02-24 [2] CRAN (R 4.4.0)
fs                  1.6.5      2024-10-30 [2] CRAN (R 4.4.1)
furrr               0.3.1      2022-08-15 [2] CRAN (R 4.4.0)
future              1.34.0     2024-07-29 [2] CRAN (R 4.4.1)
future.apply        1.11.3     2024-10-27 [2] CRAN (R 4.4.1)
gdtools             0.4.1      2024-11-04 [2] CRAN (R 4.4.1)
generics            0.1.3      2022-07-05 [2] CRAN (R 4.4.0)
ggplot2           * 3.5.1      2024-04-23 [2] CRAN (R 4.4.0)
gld                 2.6.7      2025-01-17 [2] CRAN (R 4.4.2)
globals             0.16.3     2024-03-08 [2] CRAN (R 4.4.0)
glue                1.8.0      2024-09-30 [2] CRAN (R 4.4.1)
goftest             1.2-3      2021-10-07 [2] CRAN (R 4.4.0)
gower               1.0.2      2024-12-17 [2] CRAN (R 4.4.2)
GPfit               1.0-8      2019-02-08 [2] CRAN (R 4.4.0)
gridExtra           2.3        2017-09-09 [2] CRAN (R 4.4.0)
gtable              0.3.6      2024-10-25 [2] CRAN (R 4.4.1)
hardhat             1.4.1      2025-01-31 [2] CRAN (R 4.4.2)
haven               2.5.4      2023-11-30 [2] CRAN (R 4.4.0)
hms                 1.1.3      2023-03-21 [2] CRAN (R 4.4.0)
htmltools         * 0.5.8.1    2024-04-04 [2] CRAN (R 4.4.0)
htmlwidgets         1.6.4      2023-12-06 [2] CRAN (R 4.4.0)
httpuv              1.6.15     2024-03-26 [2] CRAN (R 4.4.0)
httr                1.4.7      2023-08-15 [2] CRAN (R 4.4.0)
infer             * 1.0.7      2024-03-25 [2] CRAN (R 4.4.0)
ipred               0.9-15     2024-07-18 [2] CRAN (R 4.4.1)
iterators           1.0.14     2022-02-05 [2] CRAN (R 4.4.0)
janitor           * 2.2.1      2024-12-22 [2] CRAN (R 4.4.2)
jsonlite          * 1.8.9      2024-09-20 [2] CRAN (R 4.4.1)
kableExtra        * 1.4.0      2024-01-24 [2] CRAN (R 4.4.0)
kernlab           * 0.9-33     2024-08-13 [2] CRAN (R 4.4.1)
KernSmooth          2.23-26    2025-01-01 [2] CRAN (R 4.4.2)
```

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knitr             * 1.49       2024-11-08 [2] CRAN (R 4.4.1)
later               1.4.1      2024-11-27 [2] CRAN (R 4.4.2)
lattice           * 0.22-6     2024-03-20 [2] CRAN (R 4.4.0)
lava                1.8.1      2025-01-12 [2] CRAN (R 4.4.2)
lazyeval            0.2.2      2019-03-15 [2] CRAN (R 4.4.0)
lhs                 1.2.0      2024-06-30 [2] CRAN (R 4.4.1)
lifecycle           1.0.4      2023-11-07 [2] CRAN (R 4.4.0)
listenv             0.9.1      2024-01-29 [2] CRAN (R 4.4.0)
lmom                3.2        2024-09-30 [2] CRAN (R 4.4.1)
lubridate         * 1.9.4      2024-12-08 [2] CRAN (R 4.4.2)
magrittr            2.0.3      2022-03-30 [2] CRAN (R 4.4.0)
MASS                7.3-64     2025-01-04 [2] CRAN (R 4.4.2)
Matrix              1.7-2      2025-01-23 [2] CRAN (R 4.4.2)
memoise             2.0.1      2021-11-26 [2] CRAN (R 4.4.0)
mime                0.12       2021-09-28 [2] CRAN (R 4.4.0)
miniUI              0.1.1.1    2018-05-18 [2] CRAN (R 4.4.0)
minpack.lm          1.2-4      2023-09-11 [2] CRAN (R 4.4.0)
mnormt              2.1.1      2022-09-26 [2] CRAN (R 4.4.0)
modeldata         * 1.4.0      2024-06-19 [2] CRAN (R 4.4.0)
ModelMetrics        1.2.2.2    2020-03-17 [2] CRAN (R 4.4.0)
munsell             0.5.1      2024-04-01 [2] CRAN (R 4.4.0)
mvtnorm             1.3-3      2025-01-10 [2] CRAN (R 4.4.2)
nlme                3.1-167    2025-01-27 [2] CRAN (R 4.4.2)
nnet                7.3-20     2025-01-01 [2] CRAN (R 4.4.2)
nortest             1.0-4      2015-07-30 [2] CRAN (R 4.4.0)
officer             0.6.7      2024-10-09 [2] CRAN (R 4.4.1)
olsrr             * 0.6.1      2024-11-06 [2] CRAN (R 4.4.1)
openssl             2.3.1      2025-01-09 [2] CRAN (R 4.4.2)
pander              0.6.5      2022-03-18 [2] CRAN (R 4.4.0)
parallelly          1.42.0     2025-01-30 [2] CRAN (R 4.4.2)
parsnip           * 1.2.1      2024-03-22 [2] CRAN (R 4.4.0)
pillar              1.10.1     2025-01-07 [2] CRAN (R 4.4.2)
pkgbuild            1.4.6      2025-01-16 [2] CRAN (R 4.4.2)
pkgconfig           2.0.3      2019-09-22 [2] CRAN (R 4.4.0)
pkgload             1.4.0      2024-06-28 [2] CRAN (R 4.4.1)
plotly            * 4.10.4     2024-01-13 [2] CRAN (R 4.4.0)
plyr                1.8.9      2023-10-02 [2] CRAN (R 4.4.0)
pROC                1.18.5     2023-11-01 [2] CRAN (R 4.4.0)
processx            3.8.5      2025-01-08 [2] CRAN (R 4.4.2)
prodlim             2024.06.25 2024-06-24 [2] CRAN (R 4.4.0)
profvis             0.4.0      2024-09-20 [2] CRAN (R 4.4.1)
promises            1.3.2      2024-11-28 [2] CRAN (R 4.4.2)
proxy               0.4-27     2022-06-09 [2] CRAN (R 4.4.0)
ps                  1.8.1      2024-10-28 [2] CRAN (R 4.4.1)
psych             * 2.4.12     2024-12-23 [2] CRAN (R 4.4.2)
purrr             * 1.0.2      2023-08-10 [2] CRAN (R 4.4.0)
R6                  2.5.1      2021-08-19 [2] CRAN (R 4.4.0)
ragg                1.3.3      2024-09-11 [2] CRAN (R 4.4.1)
rappdirs            0.3.3      2021-01-31 [2] CRAN (R 4.4.1)
RColorBrewer      * 1.1-3      2022-04-03 [2] CRAN (R 4.4.0)
Rcpp                1.0.14     2025-01-12 [2] CRAN (R 4.4.2)
readr             * 2.1.5      2024-01-10 [2] CRAN (R 4.4.0)
readxl            * 1.4.3      2023-07-06 [2] CRAN (R 4.4.0)
recipes           * 1.1.0      2024-07-04 [2] CRAN (R 4.4.1)
```

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remotes             2.5.0      2024-03-17 [2] CRAN (R 4.4.0)
reshape2            1.4.4      2020-04-09 [2] CRAN (R 4.4.0)
rlang               1.1.5      2025-01-17 [2] CRAN (R 4.4.2)
rmarkdown         * 2.29       2024-11-04 [1] CRAN (R 4.4.2)
robustbase          0.99-4-1   2024-09-27 [2] CRAN (R 4.4.1)
rootSolve           1.8.2.4    2023-09-21 [2] CRAN (R 4.4.0)
rpart               4.1.24     2025-01-07 [2] CRAN (R 4.4.2)
rsample           * 1.2.1      2024-03-25 [2] CRAN (R 4.4.0)
rstudioapi          0.17.1     2024-10-22 [2] CRAN (R 4.4.1)
Rttf2pt1            1.3.12     2023-01-22 [2] CRAN (R 4.4.0)
rvest               1.0.4      2024-02-12 [2] CRAN (R 4.4.0)
scales            * 1.3.0      2023-11-28 [2] CRAN (R 4.4.0)
sessioninfo         1.2.2      2021-12-06 [2] CRAN (R 4.4.0)
sf                  1.0-19     2024-11-05 [1] CRAN (R 4.4.2)
shiny               1.10.0     2024-12-14 [2] CRAN (R 4.4.2)
snakecase           0.11.1     2023-08-27 [2] CRAN (R 4.4.0)
stringi             1.8.4      2024-05-06 [2] CRAN (R 4.4.0)
stringr           * 1.5.1      2023-11-14 [2] CRAN (R 4.4.0)
survival            3.8-3      2024-12-17 [2] CRAN (R 4.4.2)
svglite             2.1.3      2023-12-08 [2] CRAN (R 4.4.0)
systemfonts         1.2.1      2025-01-20 [2] CRAN (R 4.4.2)
terra               1.8-10     2025-01-14 [1] CRAN (R 4.4.2)
textshaping         1.0.0      2025-01-20 [2] CRAN (R 4.4.2)
tibble            * 3.2.1      2023-03-20 [2] CRAN (R 4.4.0)
tidymodels        * 1.2.0      2024-03-25 [2] CRAN (R 4.4.0)
tidyr             * 1.3.1      2024-01-24 [2] CRAN (R 4.4.0)
tidyselect          1.2.1      2024-03-11 [2] CRAN (R 4.4.0)
tidyverse         * 2.0.0      2023-02-22 [2] CRAN (R 4.4.0)
timechange          0.3.0      2024-01-18 [2] CRAN (R 4.4.1)
timeDate            4041.110   2024-09-22 [2] CRAN (R 4.4.1)
tinytex           * 0.54       2024-11-01 [2] CRAN (R 4.4.1)
tune              * 1.2.1      2024-04-18 [2] CRAN (R 4.4.0)
tzdb                0.4.0      2023-05-12 [2] CRAN (R 4.4.0)
units               0.8-5      2023-11-28 [2] CRAN (R 4.4.0)
urlchecker          1.0.1      2021-11-30 [2] CRAN (R 4.4.0)
useful            * 1.2.6.1    2023-10-24 [2] CRAN (R 4.4.0)
usethis             3.1.0      2024-11-26 [2] CRAN (R 4.4.2)
uuid                1.2-1      2024-07-29 [2] CRAN (R 4.4.1)
vctrs               0.6.5      2023-12-01 [2] CRAN (R 4.4.0)
viridisLite         0.4.2      2023-05-02 [2] CRAN (R 4.4.0)
webshot           * 0.5.5      2023-06-26 [2] CRAN (R 4.4.0)
webshot2          * 0.1.1      2023-08-11 [2] CRAN (R 4.4.0)
websocket           1.4.2      2024-07-22 [2] CRAN (R 4.4.1)
withr               3.0.2      2024-10-28 [2] CRAN (R 4.4.1)
workflows         * 1.1.4      2024-02-19 [2] CRAN (R 4.4.0)
workflowsets      * 1.1.0      2024-03-21 [2] CRAN (R 4.4.0)
xfun                0.50       2025-01-07 [2] CRAN (R 4.4.2)
xml2                1.3.6      2023-12-04 [2] CRAN (R 4.4.0)
xtable              1.8-4      2019-04-21 [2] CRAN (R 4.4.0)
yaml                2.3.10     2024-07-26 [2] CRAN (R 4.4.1)
yardstick         * 1.3.2      2025-01-22 [2] CRAN (R 4.4.2)
zip                 2.3.2      2025-02-01 [2] CRAN (R 4.4.2)

[1] /home/seamus/R/x86_64-redhat-linux-gnu-library/4.4
```

```
 [2] /usr/local/lib/R/library
 [3] /usr/lib64/R/library
 [4] /usr/share/R/library
```

```
# Sys.getenv() .libPaths()
```

References